(12)

AFGL-TR-82-0384
ENVIRONMENTAL RESEARCH PAPERS, NO. 814

A Study of Cirriform Clouds Over Eleven USSR Stations

YUTAKA IZUMI

14 December 1982

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METEOROLOGY DIVISION PROJECT 6670
AIR FORCE GEOPHYSICS LABORATORY
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AIR FORCE SYSTEMS COMMAND, USAF

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFGL-TR-82-0384	2. GOVT ACCESSION NO. AD-A130085	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A STUDY OF CIRRIFORM CLOUDS OVER ELEVEN USSR STATIONS		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim.
		6. PERFORMING ORG. REPORT NUMBER ERP No. 814
7. AUTHOR(s) Yutaka Izumi		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Geophysics Laboratory (LYT) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 66701202
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Geophysics Laboratory (LYT) Hanscom AFB Massachusetts 01731		12. REPORT DATE 14 December 1982
		13. NUMBER OF PAGES 148
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cirriform clouds
Liquid water content
Cloud heights
Cloud cover
Cloud thickness
Climatic probability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The frequency, top and base heights, thickness and liquid water content of cirriform clouds over 11 stations in the USSR are presented by months and by seasons and summarized for the 12-month period. Comparison is also made with aircraft observations of cirriform clouds over the European part of the USSR.

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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A Study of Cirriform Clouds Over Eleven USSR Stations

1. AFGL SECOND GENERATION MODEL AND THE 11-STATION STUDY

Cirriform clouds are normally ice crystal clouds, which are defined as being composed (almost) exclusively of ice crystals, as opposed to water droplets.[1] This report gives the results of a study of cirriform clouds for a number of stations within the USSR. The cloud study was based on data derived from the use of the Air Force Geophysics Laboratory's second generation model (AFGL-2).

The AFGL-2 model was developed by AFGL for the Environmental Definition Program (EDP) to deduce profiles of atmospheric liquid water content (LWC) values. It was devised specifically for what came to be known as the "Eleven-Station Study". The objective of this study was to generate a year-long record of vertical profiles of LWC and hydrometeor type for both clouds and precipitation for each of the eleven selected meteorological stations within the USSR. These stations are identified in Table 1 and their locations are shown in Figure 1. The stations were selected for the supposed diversity of their LWC climates as well as for the availability of suitable meteorological records. The year selected was the 12-month period from 1 February 1973 through 31 January 1974.

(Received for publication 9 December 1982)

1. McIntosh, D.H. (1972) Meteorological Glossary, Chemical Publishing Co., New York.

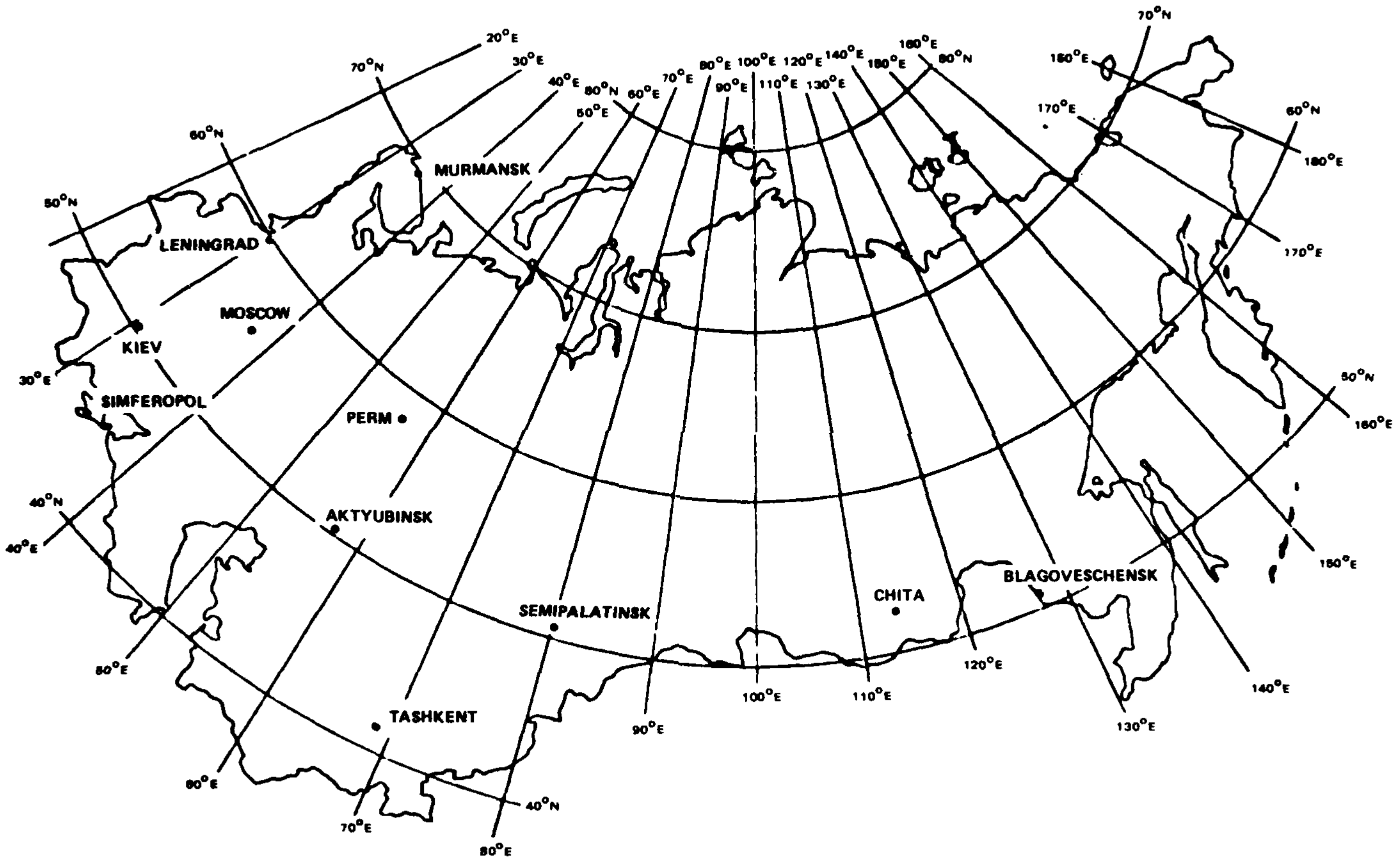

Figure 1. Goegraphical Distribution of the 11 USSR Stations of the Environmental Definition Program

Table 1. The 11 USSR Stations of the Environmental Definition Program

Station Number	Name	Latitude	Longitude
221130	Murmansk	68°58' N	33°03' E
260630	Leningrad	59° 58'N	30°18 E
275155	Moscow	55°58' N	37°25' E
333450	Kiev	50°24' N	30°27' E
339460	Simferopol	45°01 N	33°59' E
282250	Perm	58°01' N	56°18' E
352290	Aktyubinsk	50°20' N	57°13' E
361770	Semipalatinsk	50°21' N	80°15' E
384570	Tashkent	41°16' N	69°16' E
307580	Chita	52°01' N	113°19' E
315100	Blagoveschensk	50°16' N	127°30' E

The analytical procedures for AFGL-2 are described by Cunningham and Peirce[2] and Feteris et al.[3] They are tedious procedures that start with a hand analyzed, vertical, time-height cross section that incorporates all meteorological data that are systematically available for the particular location. Surface weather observations, upper-air soundings, the Northern Hemisphere Maps published by the National Oceanic and Atmospheric Administration (NOAA), the three-dimensional nephanalysis (3DNEPH) of the Air Force Global Weather Center (AFGWC), and imagery products of the Defense Meteorological Satellite Program (DMSP) were used to construct the original cross section analysis. Then, wherever clouds or precipitation are reckoned to have existed, values of LWC are assigned according to typical values for the class of hydrometeor, the temperature, the synoptic situation, and other circumstances. For each of the 11 stations, and for every 3 hours of the entire 12-month period, a vertical profile of LWC and hydrometeor distribution were extracted from the cross section. Thus, the ultimate product of the 11-station study was some 32,000 sets of data consisting of not only the LWC for each type of cloud and precipitation but also, for each cloud and precipitation layer, the amount of sky coverage, the heights of the top and base, and values of two parameters of significance in the erosion of ballistic reentry vehicles.

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2. Cunningham, R.M., and Peirce, R.M. (1974) Private communication.
3. Feteris, P.J., Lisa, A.S., and Bussey, A.J. (1975) Environmental Definition Program Cross Sectional Analysis: Summary of Data and Analysis Technique, AFCRL-TR-76-0002, AD A024707.

The cloud category was reserved only for liquid water drops (often supercooled) and excluded the cirriform (ice-crystal) cloud. The precipitation category was broken down into rain, large snow, small snow, and ice crystals. The cirriform cloud was thus classified as precipitation.

At altitudes where the temperature was below -25 C, the cirriform cloud layer was determined by the moisture and stability structure, by an observation from the ground, or by the texture of the cloud as viewed from the satellite. The top of the cirriform cloud was determined by the temperature lapse rate and by the moisture trend using the close relationship between the height of the cloud top and the height of the tropopause as a guide. The amount of cloud cover was determined by the ground or satellite observed upper cloud coverage, by the moisture pattern, and by the upper air trends. The LWC values assigned to the cirriform cloud layer were determined by reference to SAMS (Sandia Air Force Materials Study), EDP aircraft and radar data, and to various references in the U. S., British, and Russian literature.

This report on cirriform clouds over the 11 selected USSR stations will discuss the monthly, seasonal, and annual variations of the frequency, height, thickness, and LWC of the cloud layers.

The monthly analyses are presented to show the variability of the data from month to month. Later on, the seasonal and annual analyses are arranged to show the differences between stations that would be obscured by the month-to-month variations if a monthly analysis of this type were attempted.

In the following sections the terms cirrus or cirrus cloud will be used interchangeably with cirriform cloud. Although cirrus, in the strict sense of the word, is one of the three genera of cirriform clouds (the others being cirrostratus and cirrocumulus), the AFGL-2 model grouped together indiscriminately all cirriform types, including thunderstorm cirrus, under the precipitation category simply as ice-crystal clouds. Thus the term cirrus used in this report can only refer to all cirriform types collectively. Also the term cloud cover used in the text and in the figures refers only to the cirrus cloud cover and not to the total sky coverage.

2. CIRRIFORM CLOUD STUDY BY MONTHS

2.1 Frequency of Cirrus

The frequency of occurrence of cirrus over a particular station was determined from the number of 3-hour periods that reported ice-crystal cloud layers. The total number of occurrences of cirrus recorded for the 11 stations during the 12-month period was 16,217.

Figures 2a through 2k show, for each of the 11 stations, the monthly frequencies of cirrus clouds with coverages of 1/10th and above (clear bars) and of 5/10th and above (vertically striped bars). Also shown is the number of occasions a second layer of cirrus (vertically and horizontally striped bars) was observed.

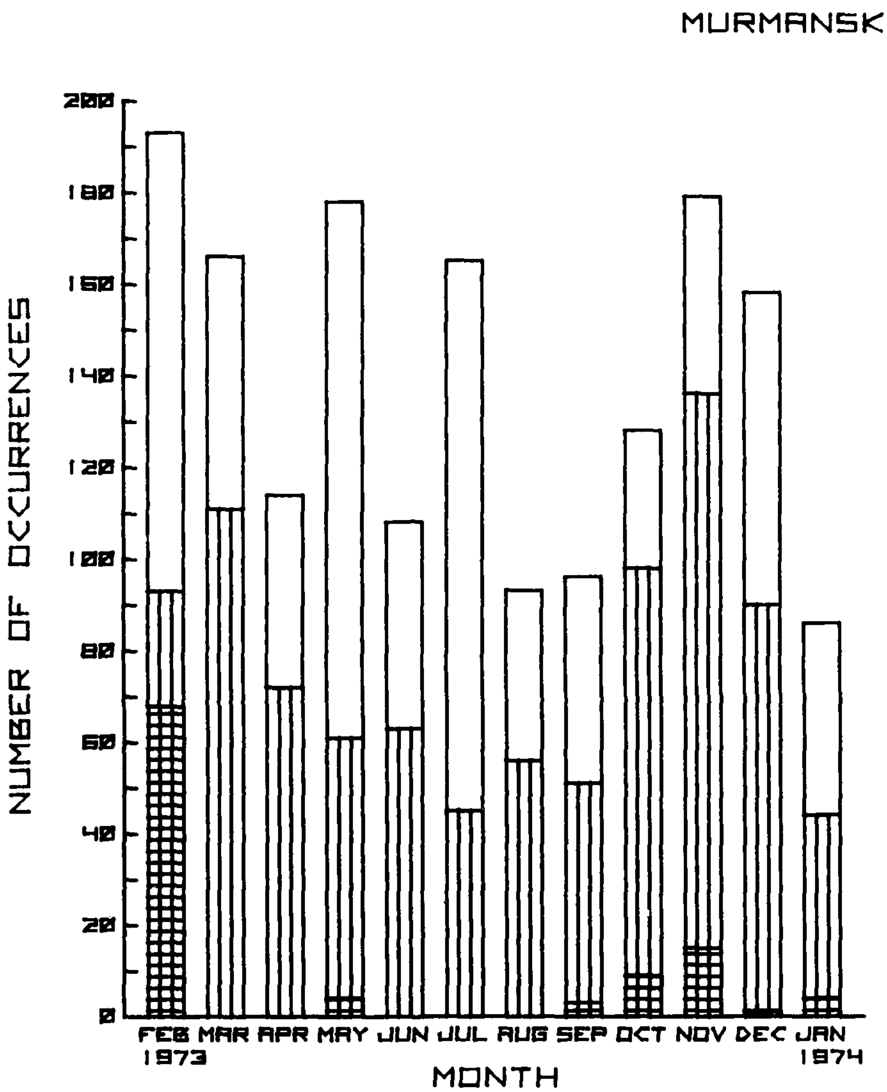

Figure 2a. Monthly Frequency of Cirriform Cloud Occurrence at Murmansk. (Clear bars represent cirrus coverage > 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

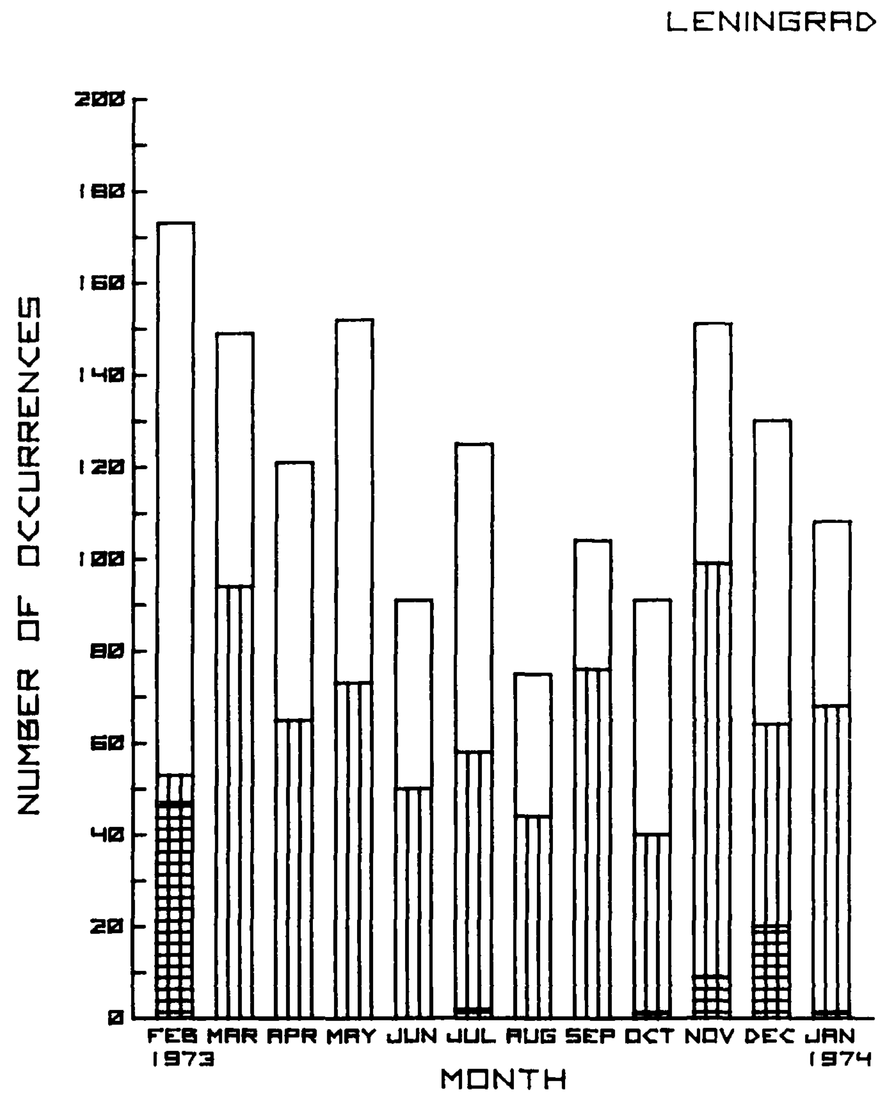

Figure 2b. Monthly Frequency of Cirriform Cloud Occurrence at Leningrad. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

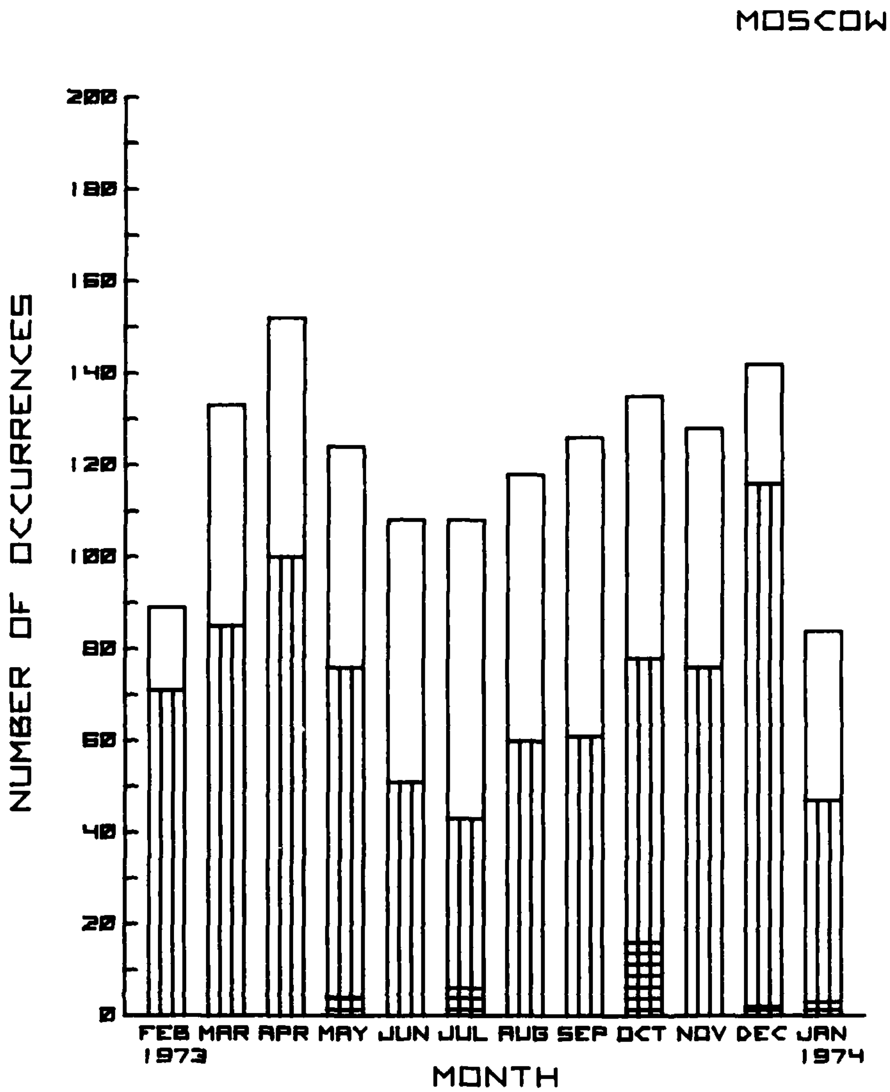

Figure 2c. Monthly Frequency of Cirriform Cloud Occurrence at Moscow. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

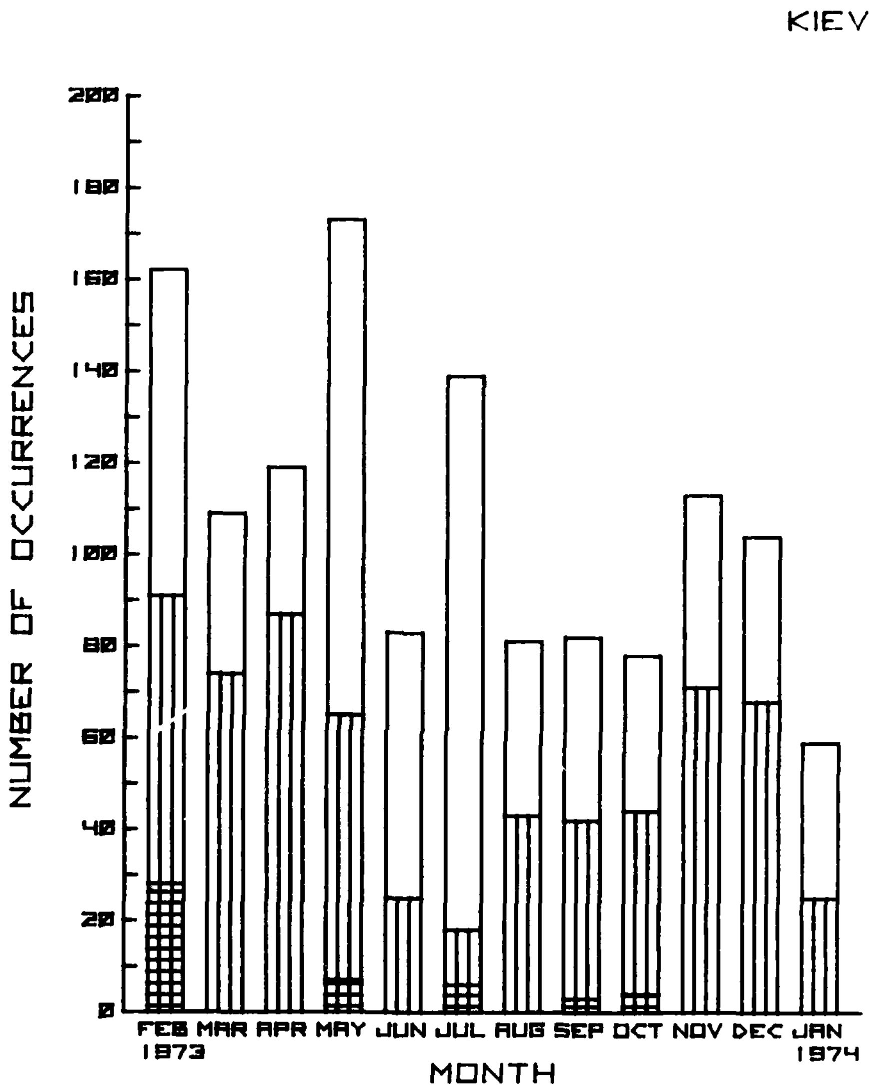

Figure 2d. Monthly Frequency of Cirriform Cloud Occurrence at Kiev. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

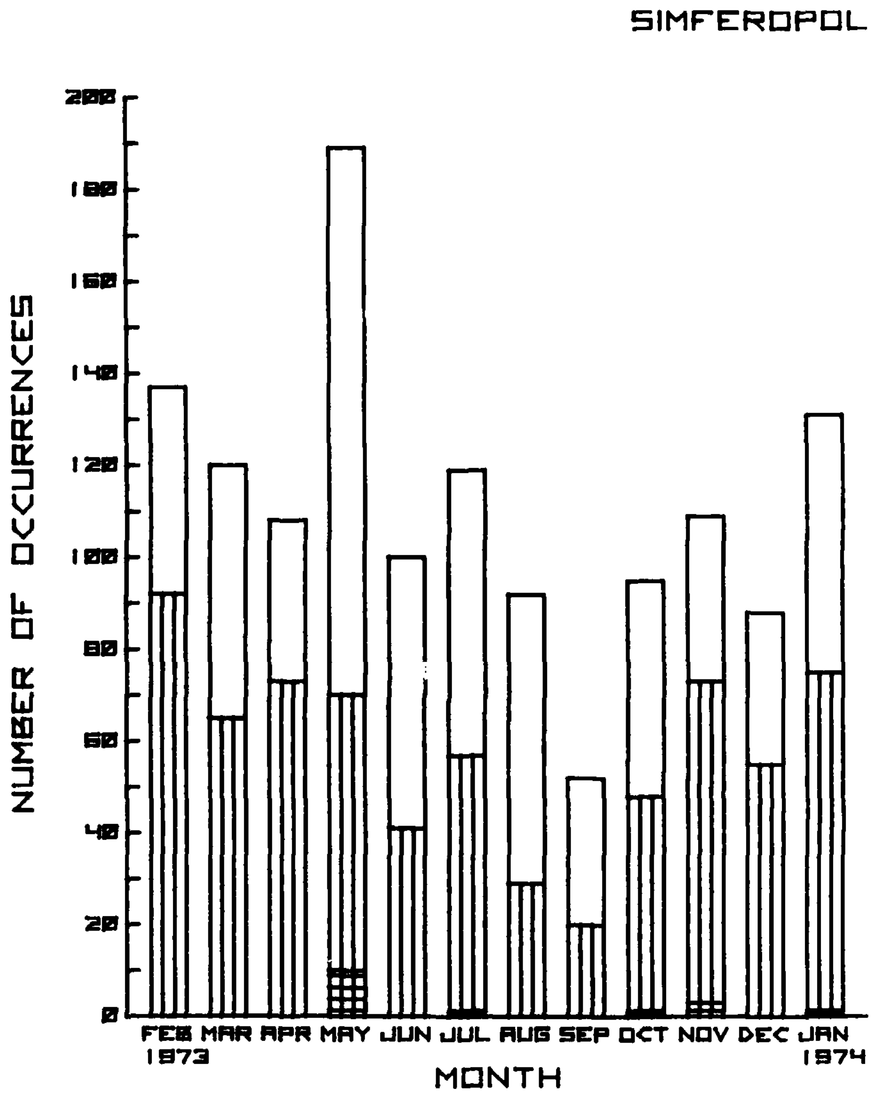

Figure 2e. Monthly Frequency of Cirriform Cloud Occurrence at Simferopol. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage > 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

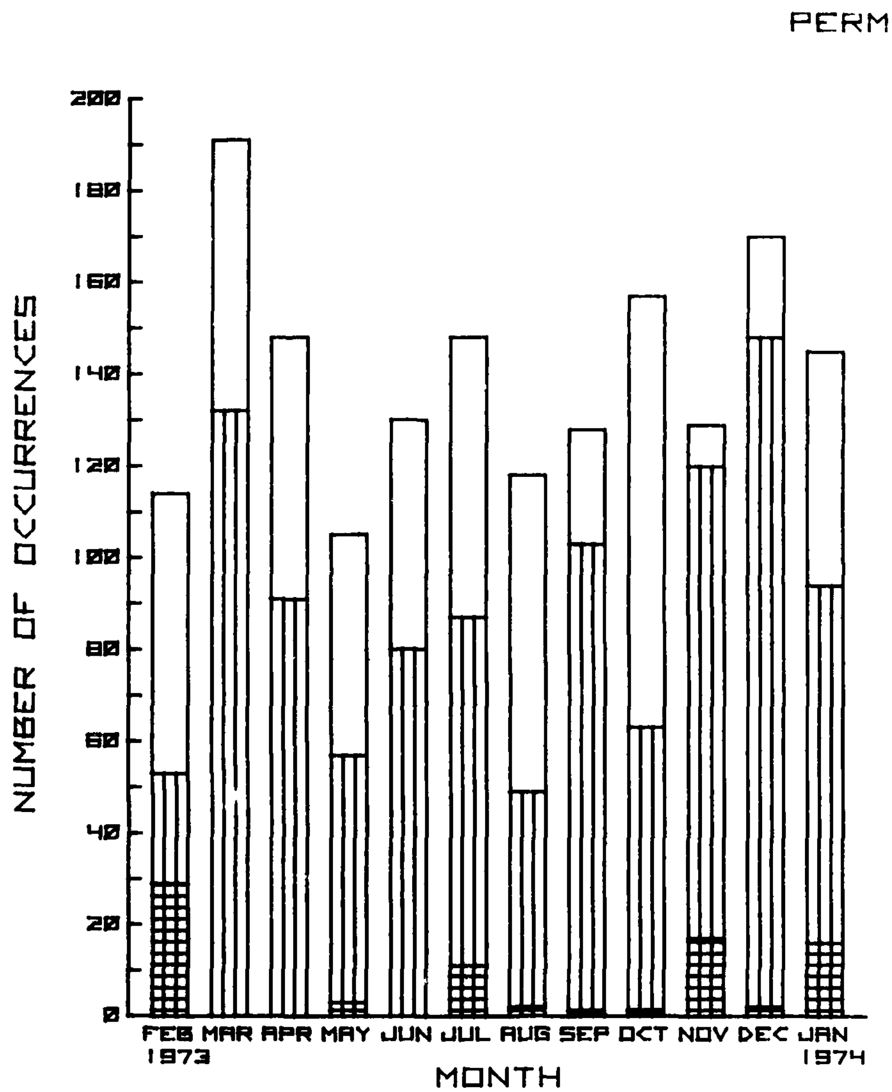

Figure 2f. Monthly Frequency of Cirriform Cloud Occurrence at Perm. (Clear bars represent cirrus coverage > 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

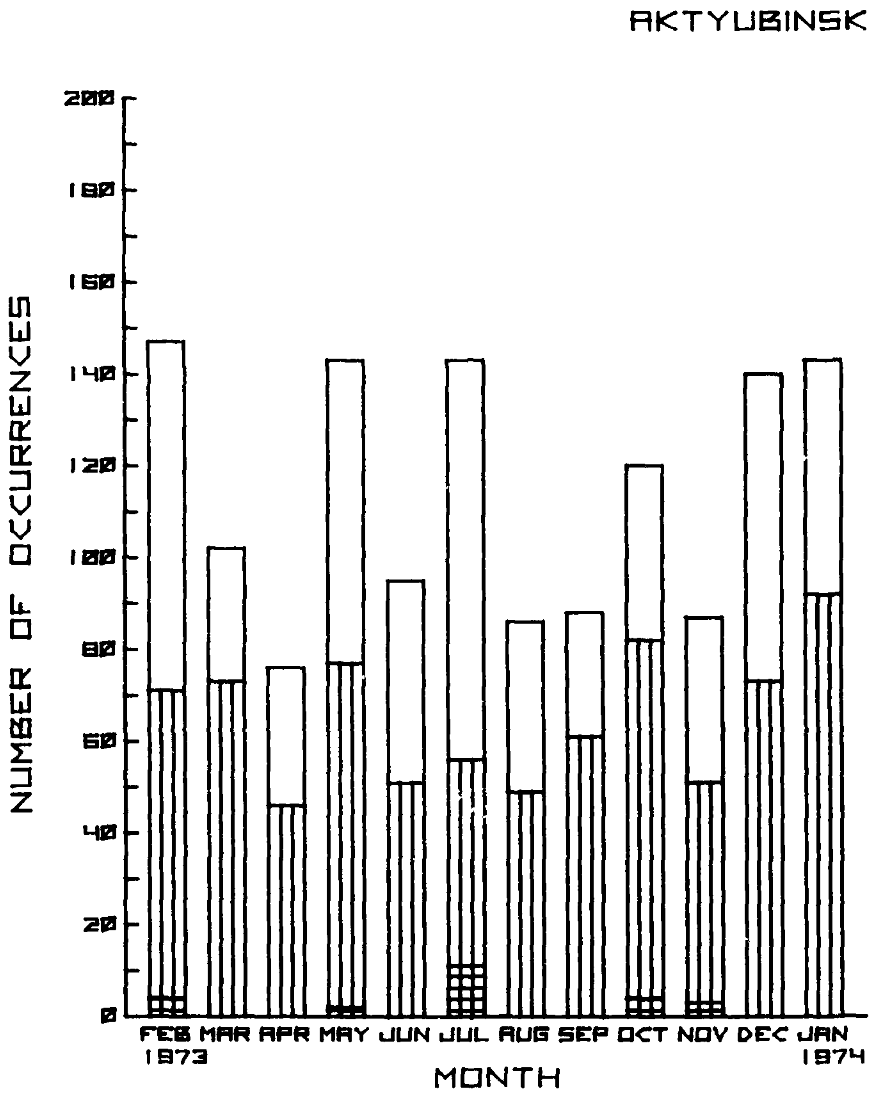

Figure 2g. Monthly Frequency of Cirriform Cloud Occurrence at Aktyubinsk. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

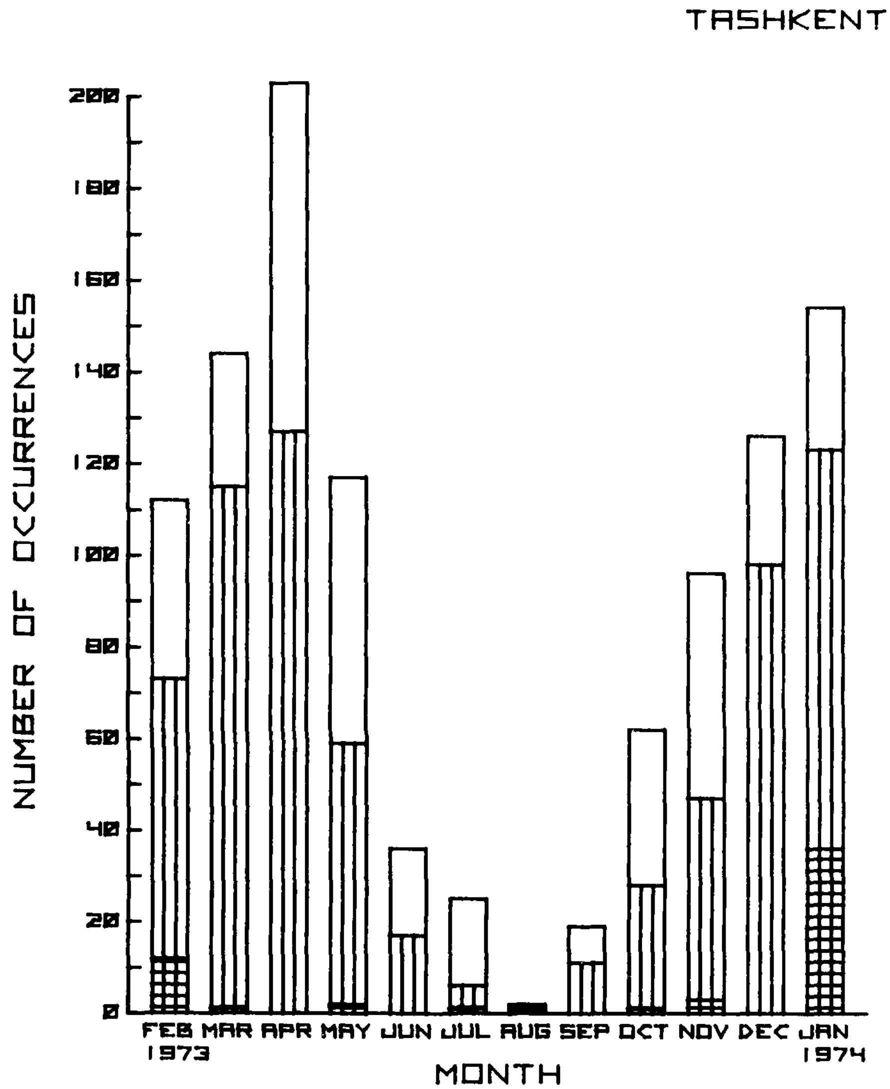

Figure 2h. Monthly Frequency of Cirriform Cloud Occurrence at Tashkent. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

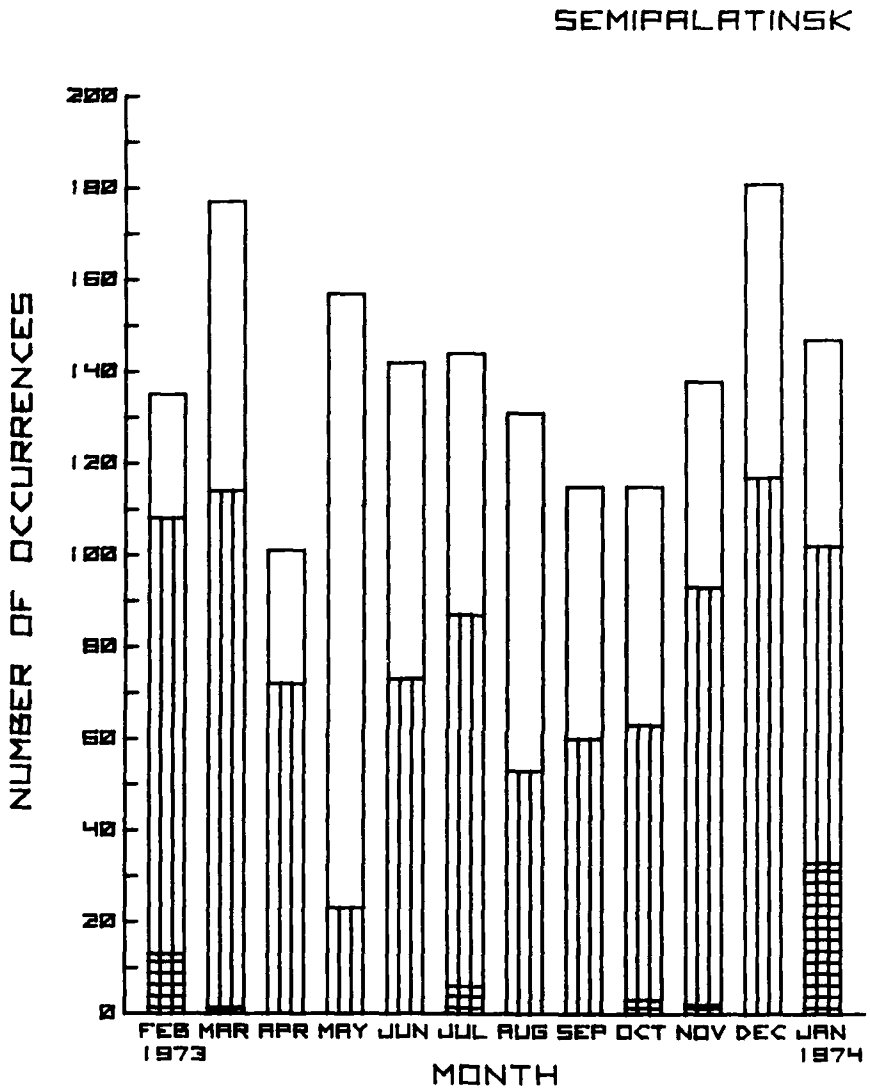

Figure 2i. Monthly Frequency of Cirriform Cloud Occurrence at Semipalatinsk. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

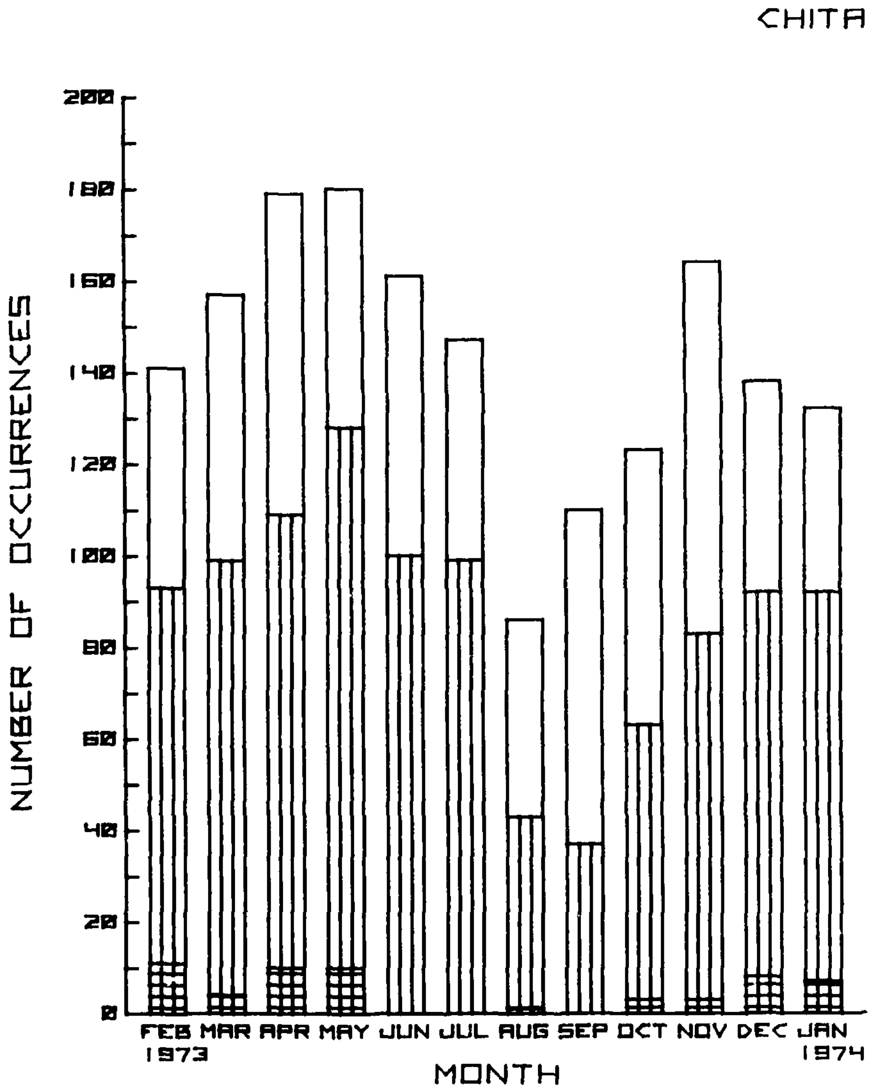

Figure 2j. Monthly Frequency of Cirriform Cloud Occurrence at Chita. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

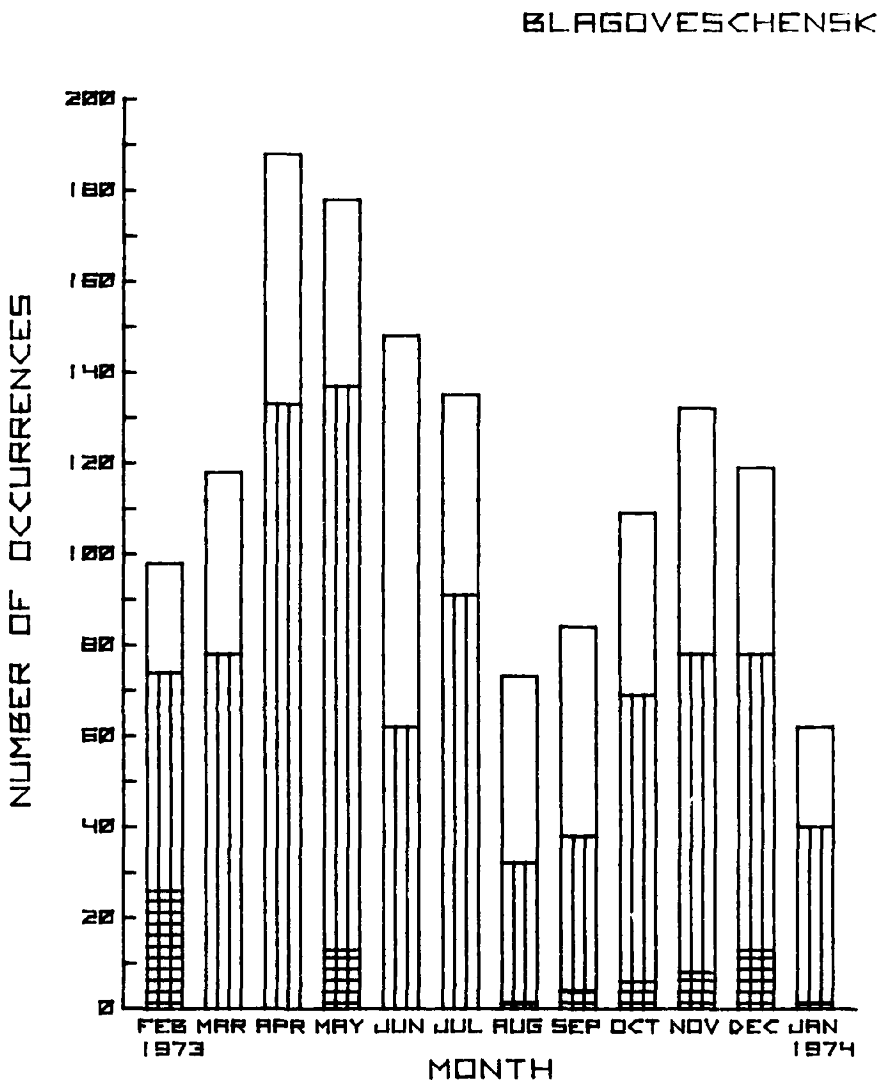

Figure 2k. Monthly Frequency of Cirriform Cloud Occurrence at Blagoveschensk. (Clear bars represent cirrus coverage ≥ 1/10th, vertically striped bars represent cirrus coverage ≥ 5/10th, and vertically and horizontally striped bars represent the number of second layers of cirrus)

For the two categories of cirrus layer coverages, the stations Tashkent, Chita, and perhaps, Blagoveschensk are the only ones that exhibited an orderly and systematic change in the number of occurrences from month to month. The monthly variations displayed by the other stations are too erratic and too confusing for a comprehensive discussion. The highest number of occurrences of 1/10 or greater coverage was 203 (of a maximum possible number of 240) at Tashkent in April and the lowest was only 2, also at Tashkent, in August. The number of occurrences of 5/10 and greater coverage ranged from 148 at Perm in December to only 1 at Tashkent in August. The component part bar charts show wide variations in the differences in frequency between the two categories of cloud cover. Small differences are noted for Moscow in December and for Perm in September, November, and December, while large differences are evident for Kiev in July and for Semipalatinsk in May. The occurrence of coverage of 5/10 or greater, expressed as a percentage of the occurrence of coverage of at least 1/10, ranged from a high of 93.0 at Perm in November to a low of 13.0 at Kiev in July. To complement these figures, the percentage frequencies of cirrus clouds with coverages of 1/10th and above and with coverages of 5/10th and above are presented in Tables 2a and 2b, respectively.

The second layers of cirrus shown in the figures were invariably found below the first or primary layers. About 80 percent of these second layers had their tops coinciding with the bases of the primary layers above. These cloud decks were stratified into two layers because of the differences in the cloud layer coverages or in the LWC values with the upper layers usually dominating the lower ones. The remaining 20 percent of second layers were detached from the primary layers above and constituted separate cloud decks. From these figures it can be seen that the second layers were most frequently observed in February with January close behind. The frequencies of the second layer with respect to the first were as high as 35.2 percent at Murmansk and 27.2 percent at Leningrad in February. No second layer was recorded during the month of June. The total number of second layers for all 11 stations and for all months was 630. A second layer occurred less than 4 percent as often as the first. In addition to the second layers, there were two cases with a third layer observed below the second one. Comparison of the 630 sets of first and second layers showed the average thicknesses of the layers to be 1.9 km for the first and 1.5 km for the second layers. The thicknesses of the two third layers were only 0.3 and 0.6 km. These multi-layered cirrus decks posed numerous problems in this study. Although the frequencies of second layers were relatively high for a few stations, particularly in winter, the total effect was small. For this reason, the second and third cirrus cloud layers will be excluded from the rest of the presentation and only the statistics of the first layers will be discussed.

Table 2a. Percentage Frequency of Cirriform Clouds

Month	MUR	LEN	MOS	KIE	SIM	PER	AKT	SEM	TAS	CHI	BLA
Feb	86.2	77.2	39.7	72.3	61.2	50.9	65.6	60.3	50.0	63.0	43.8
Mar	66.9	60.1	53.6	44.0	48.4	77.0	41.1	71.4	58.1	63.3	47.6
Apr	47.5	50.4	63.3	49.6	45.0	61.7	31.7	42.1	84.6	74.6	78.3
May	71.8	61.3	50.0	69.8	76.2	42.3	57.7	63.3	47.2	72.6	71.8
Jun	45.0	37.9	45.0	34.6	41.7	54.2	39.6	59.2	15.0	67.1	61.7
Jul	66.5	50.4	43.6	56.1	48.0	59.7	57.7	58.1	10.1	59.3	54.4
Aug	37.5	30.2	47.6	32.7	37.1	47.6	34.7	52.8	0.8	34.7	29.4
Sep	40.0	43.3	52.5	34.2	21.7	53.3	36.7	47.9	7.9	45.8	35.0
Oct	51.6	36.7	54.4	31.4	38.3	63.3	48.4	46.4	25.0	49.6	44.0
Nov	74.6	62.9	53.3	47.1	45.4	54.6	36.2	57.5	40.0	68.3	55.0
Dec	63.7	52.4	57.3	41.9	35.5	68.6	56.4	73.0	50.8	55.6	48.0
Jan	34.7	43.6	33.9	23.8	52.8	58.5	57.7	59.3	62.1	53.2	25.0

Table 2b. Percentage Frequency of Cirriform Clouds With the Cloud Layer Coverage ≥ 5/10

Month	MUR	LEN	MOS	KIE	SIM	PER	AKT	SEM	TAS	CHI	BLA
Feb	41.5	23.7	31.7	40.6	41.1	23.7	31.7	48.2	32.6	41.5	33.0
Mar	44.8	37.9	34.3	29.8	26.2	53.2	29.4	46.0	46.4	39.9	31.5
Apr	30.0	27.1	41.7	36.3	30.4	37.9	19.2	30.0	52.9	45.4	55.4
May	24.6	29.4	30.6	26.2	28.2	23.0	31.0	9.3	23.8	51.6	55.2
Jun	26.3	20.8	21.3	10.4	17.1	33.0	21.3	30.4	7.1	41.7	25.8
Jul	18.1	23.4	17.3	7.3	23.0	35.1	22.6	35.1	2.4	39.9	36.7
Aug	22.6	17.7	24.2	17.3	11.7	19.8	19.8	21.4	0.4	17.3	12.9
Sep	21.3	31.7	25.4	17.5	8.3	42.9	25.4	25.0	4.6	15.4	15.8
Oct	39.5	16.1	31.5	17.7	19.4	25.4	33.1	25.4	11.3	25.4	27.8
Nov	56.7	41.3	31.7	29.6	30.4	50.0	21.3	38.8	19.6	34.6	32.5
Dec	36.3	25.8	46.8	27.4	22.2	59.7	29.4	47.2	39.5	37.1	31.5
Jan	17.7	27.4	19.0	10.1	30.2	37.9	37.1	41.1	49.6	37.1	16.1

Figures 3a through 3k show the cumulative frequency distribution of the cirrus clouds with respect to cloud cover by month (grouped by seasons) for each of the 11 stations. (Note that the winter months are December 1973, January 1974, and February 1973.) For any amount of cirrus cloud cover in tenths the plots show the percentage of occurrence of cirrus for that amount of cloud cover and above. As expected from the previous discussions, the variations by month, by season, and by stations are too great and erratic for a meaningful discussion. These figures show that by selecting one month such as the midseason month to represent a season would be misleading, for only in a few cases does a month adequately represent a season.

2.2 Cirrus Heights and Thickness

The monthly variations of the average top and base heights together with the thickness (striped area) of the cirrus layers are presented in Figures 4a through 4k for the individual stations. Except for a few of the stations, the month-to-month changes of the top and base heights are shown to be erratic and unpredictable. The averages for the top ranged from a low of 7.0 km at Murmansk in April to a high of 11.0 km at Tashkent in May. The averages for the base ranged from 5.7 km at Leningrad in December to 9.1 km at Blagoveschensk in July (the 9.8 km average based on two samples at Tashkent in August was discounted). For most of the stations the cirrus top and base are highest during the summer and autumn months and lowest during the winter and spring months.

The monthly variations of the thickness of cirrus layers can be seen from the above figures. One notable feature is lack of relationship between the thickness and the height of the cirrus layer. The low-base cloud layers are not necessarily the thickest. For better comparison the monthly average thicknesses are shown in Figures 5a through 5f. In Figure 5f the averages (not the weighted average) of the monthly thickness values for the 11 stations are also shown as indicators of the monthly variations. The thickness values ranged from 1.0 km at Murmansk in April to 3.1 km at Moscow in October. For most of the stations the thickest cirrus layers are found during the autumn and winter months and the thinnest layers during the spring and summer months.

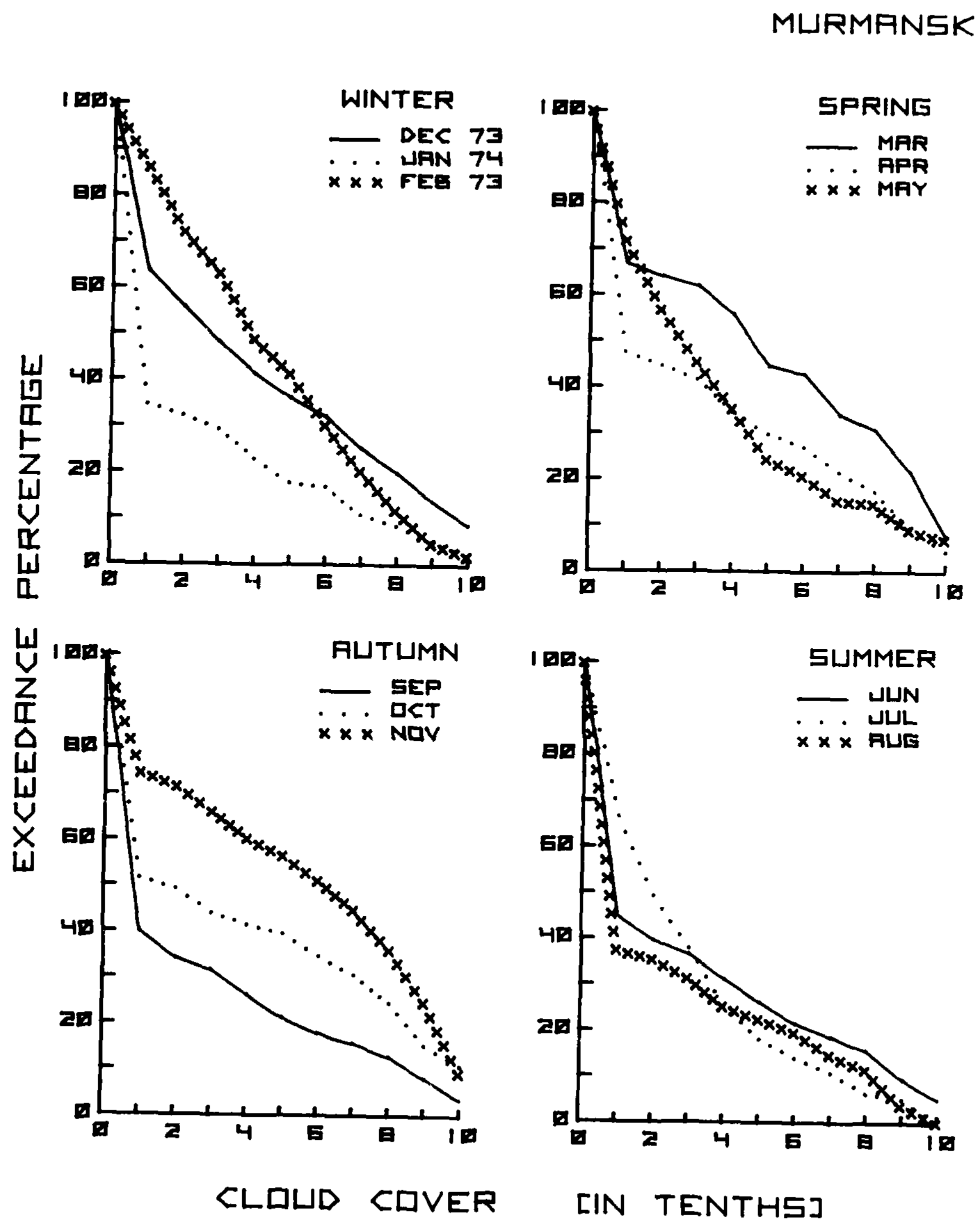

Figure 3a. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Murmansk

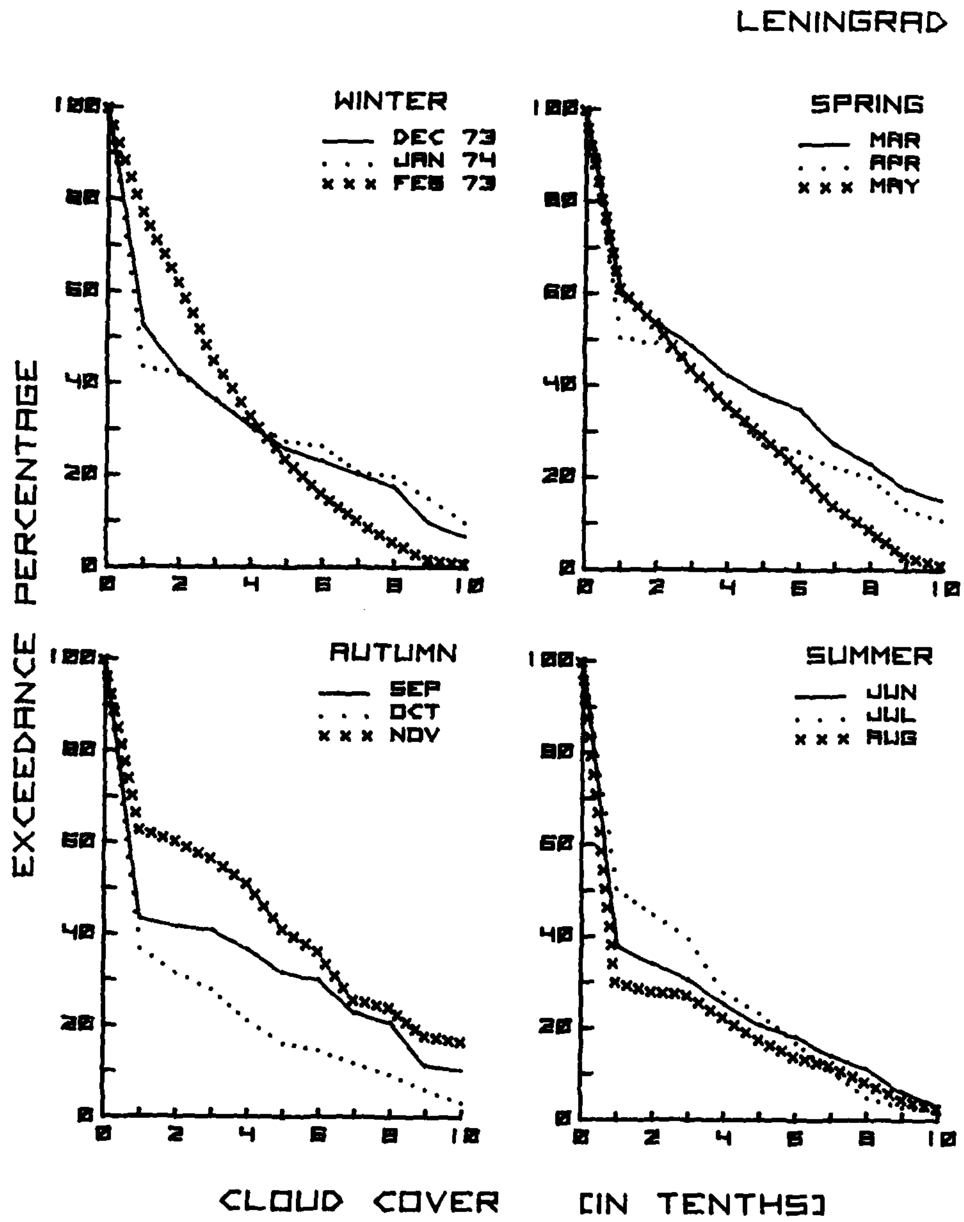

Figure 3b. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Leningrad

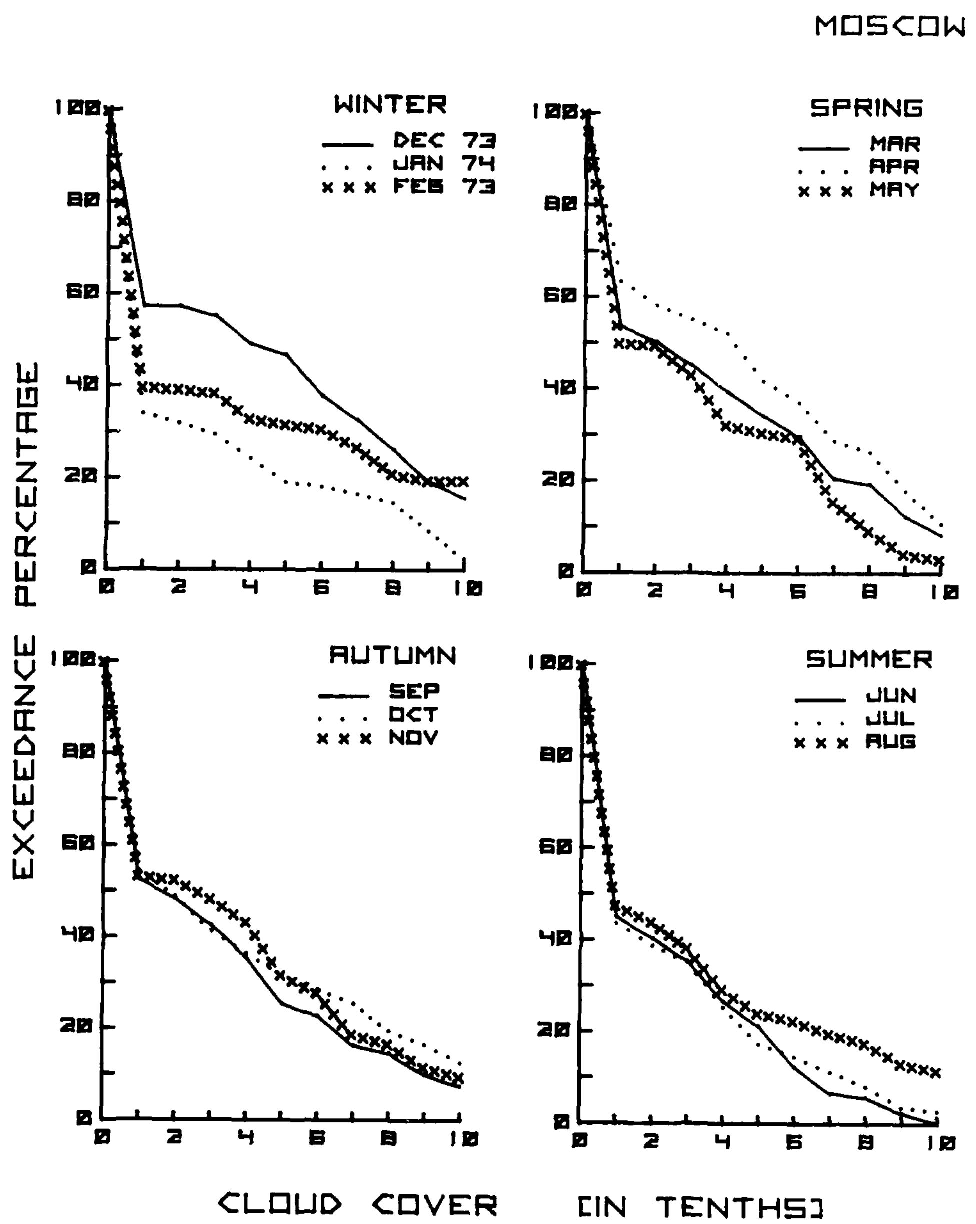

Figure 3c. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Moscow

KIEV

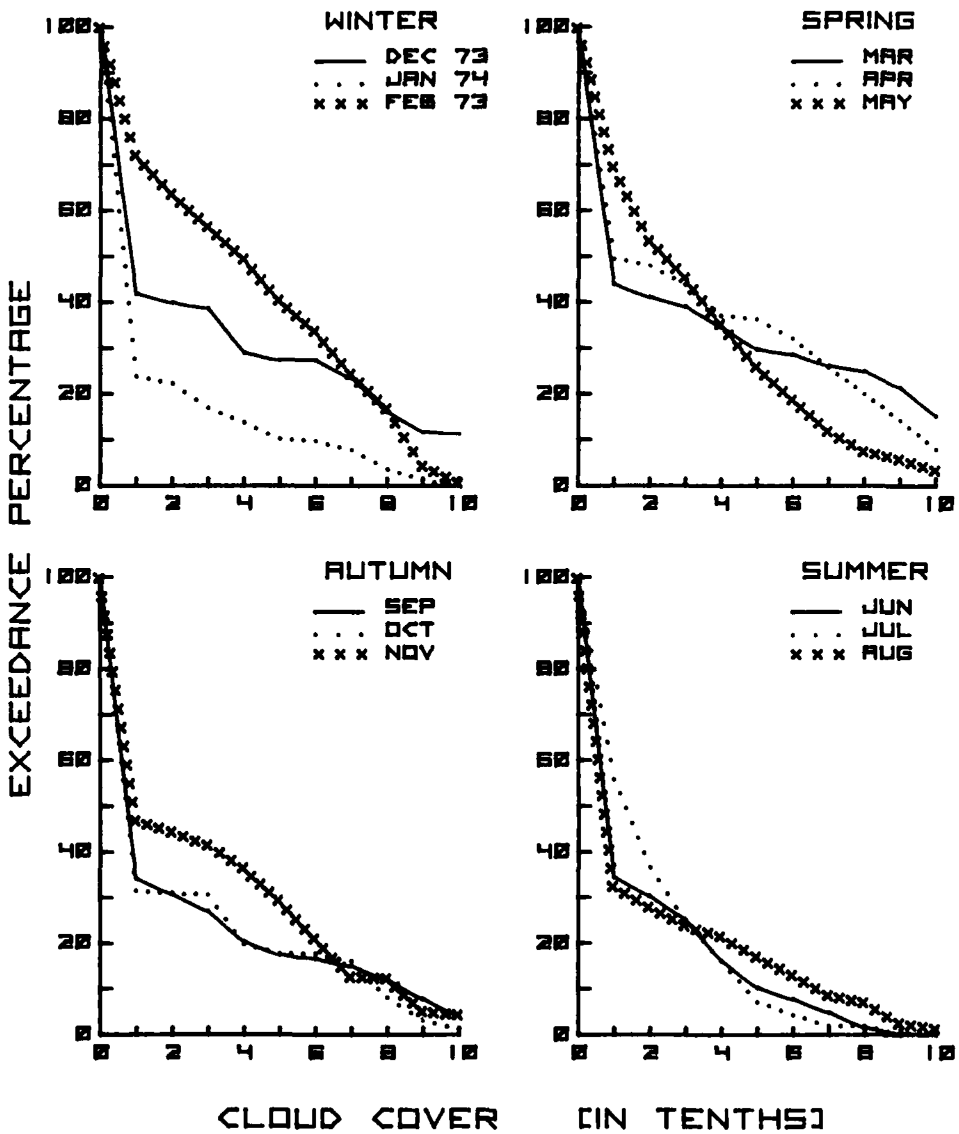

Figure 3d. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Kiev

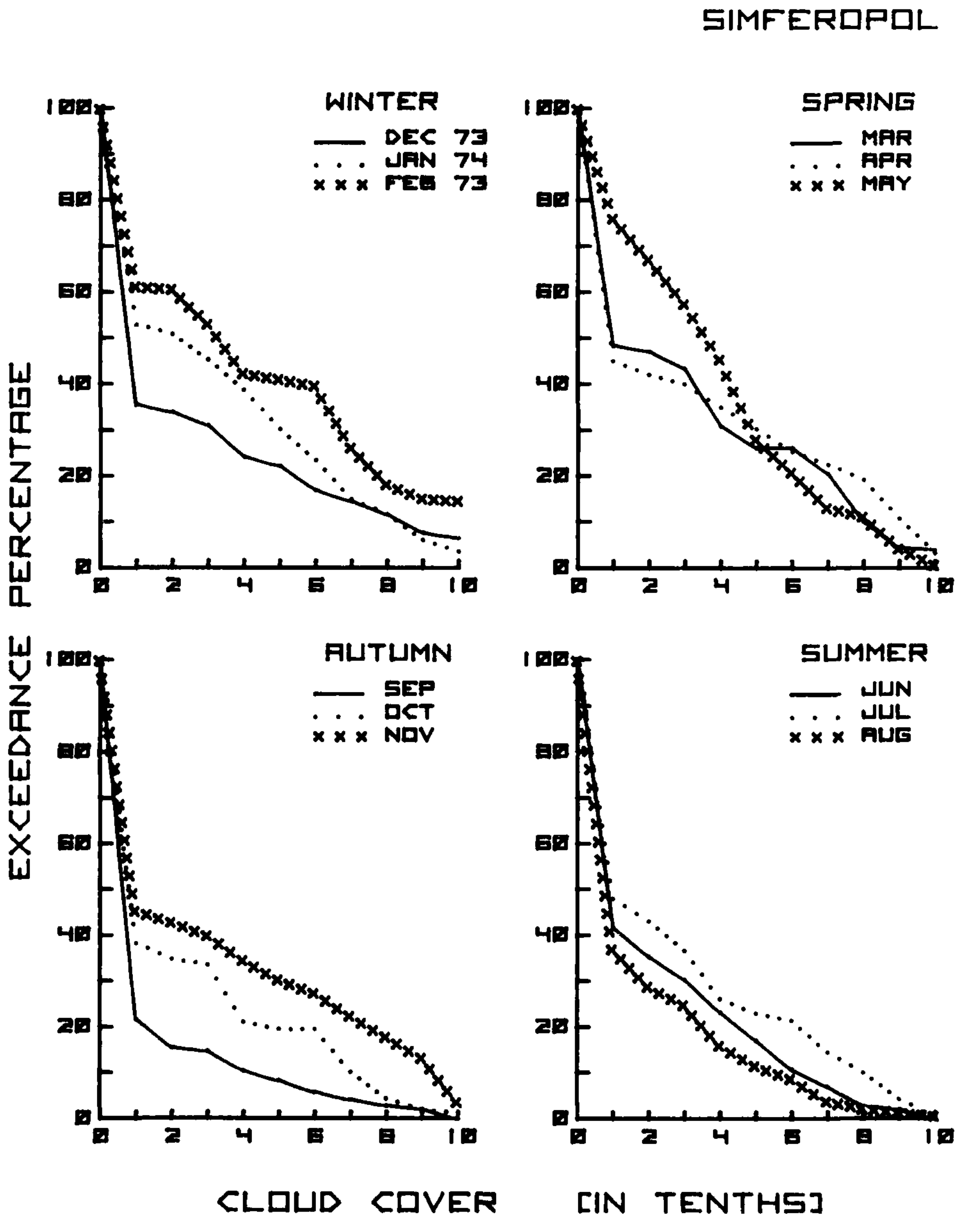

Figure 3e. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Simferopol

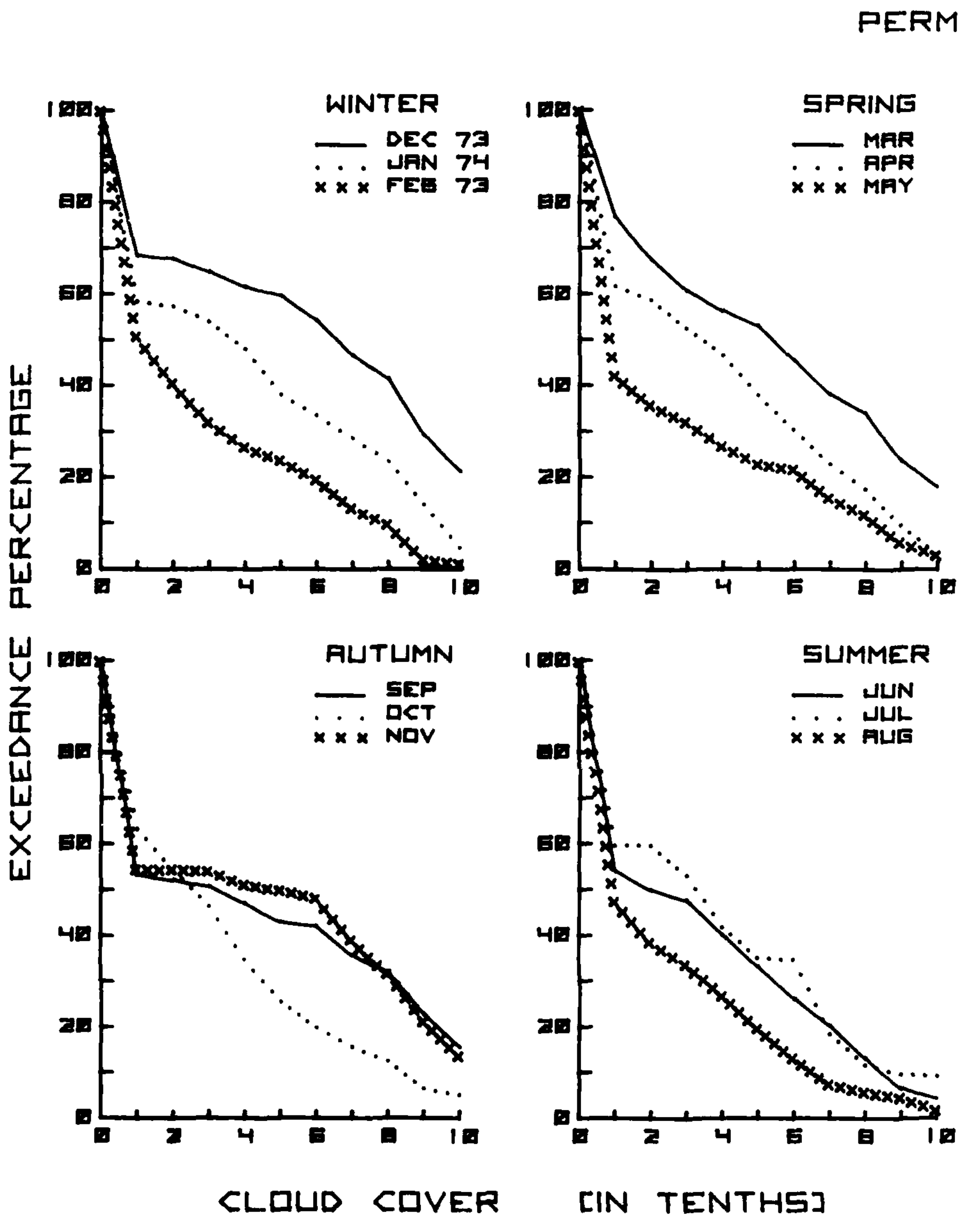

Figure 3f. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Perm

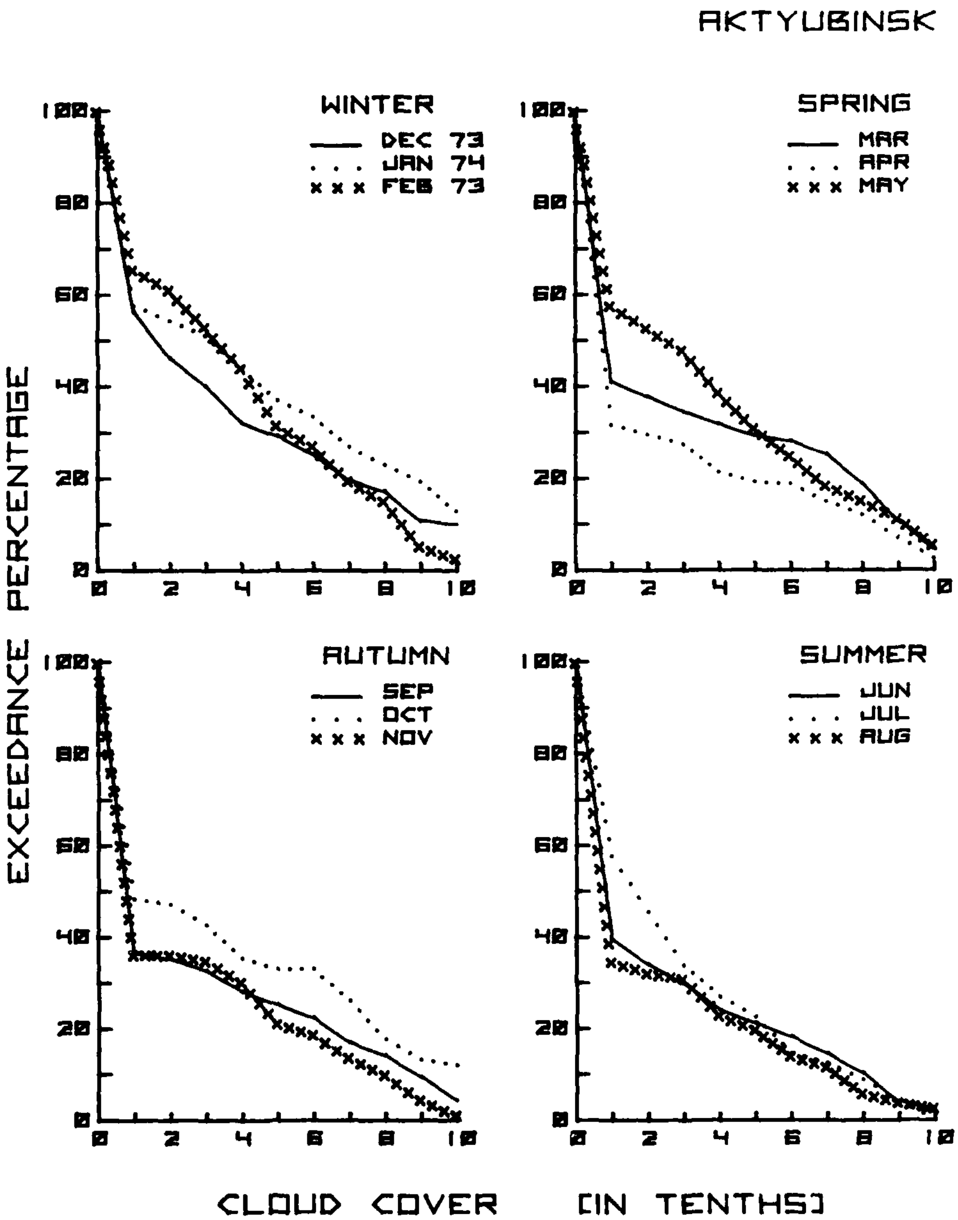

Figure 3g. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Aktyubinsk

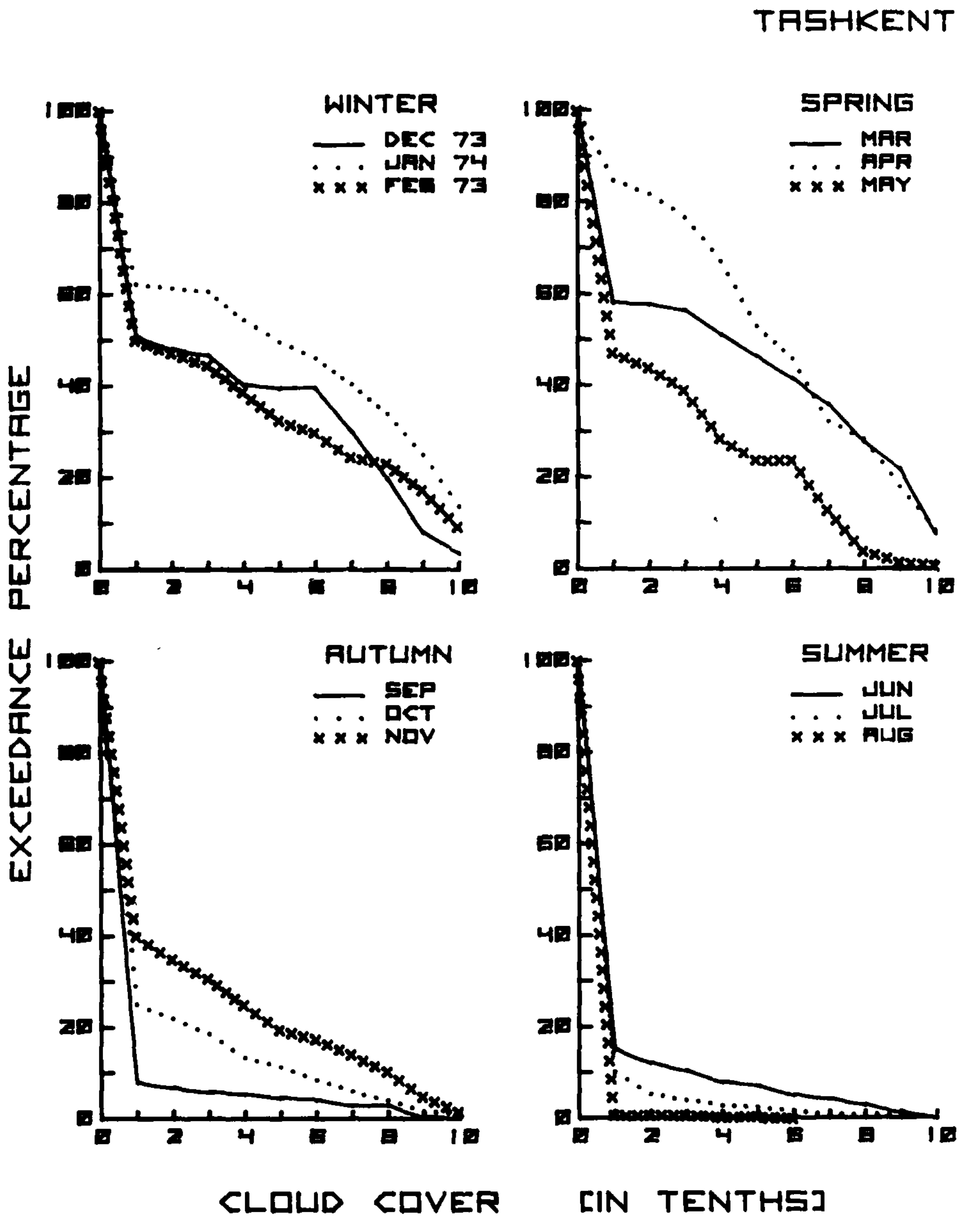

Figure 3h. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Tashkent

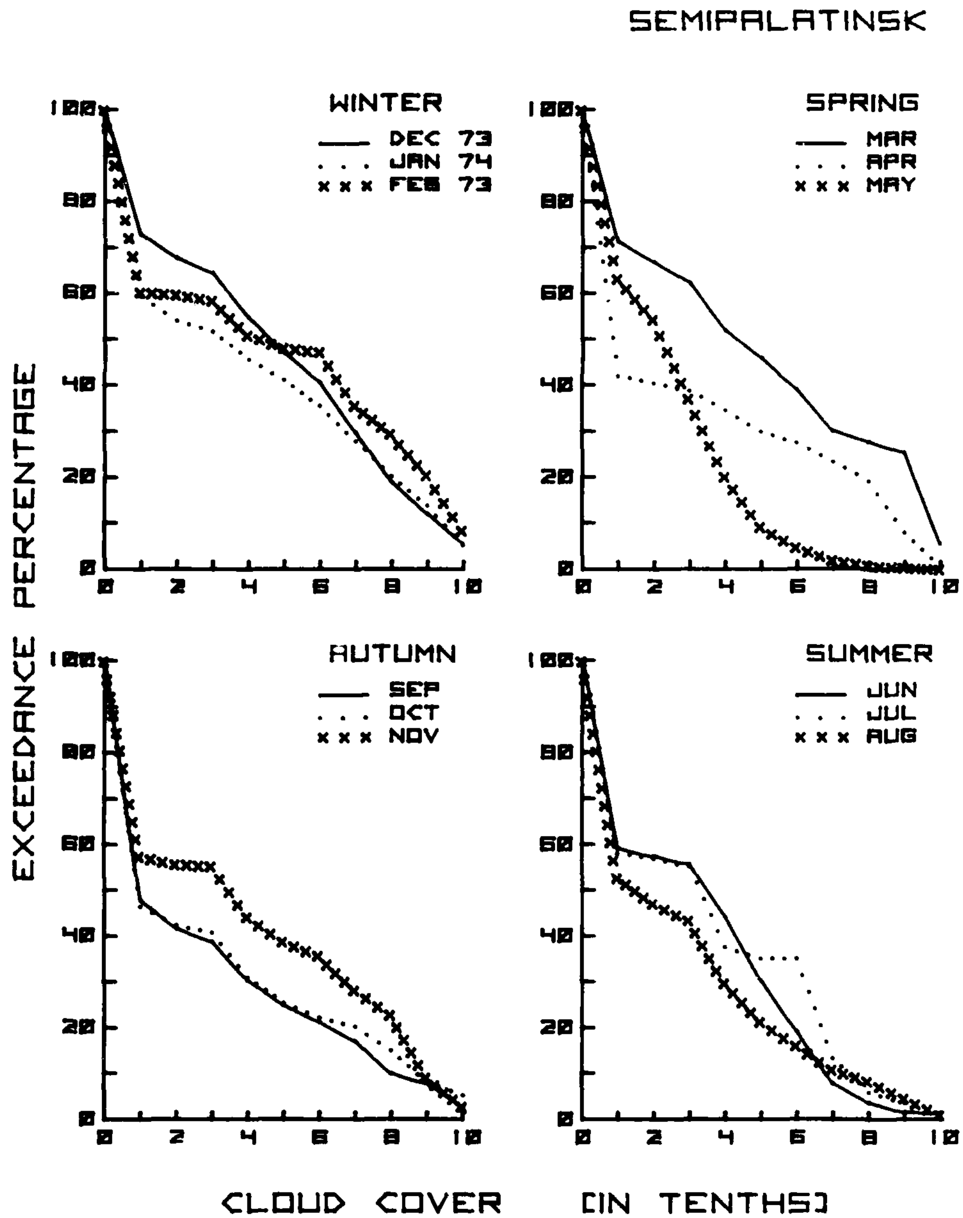

Figure 3i. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Semipalatinsk

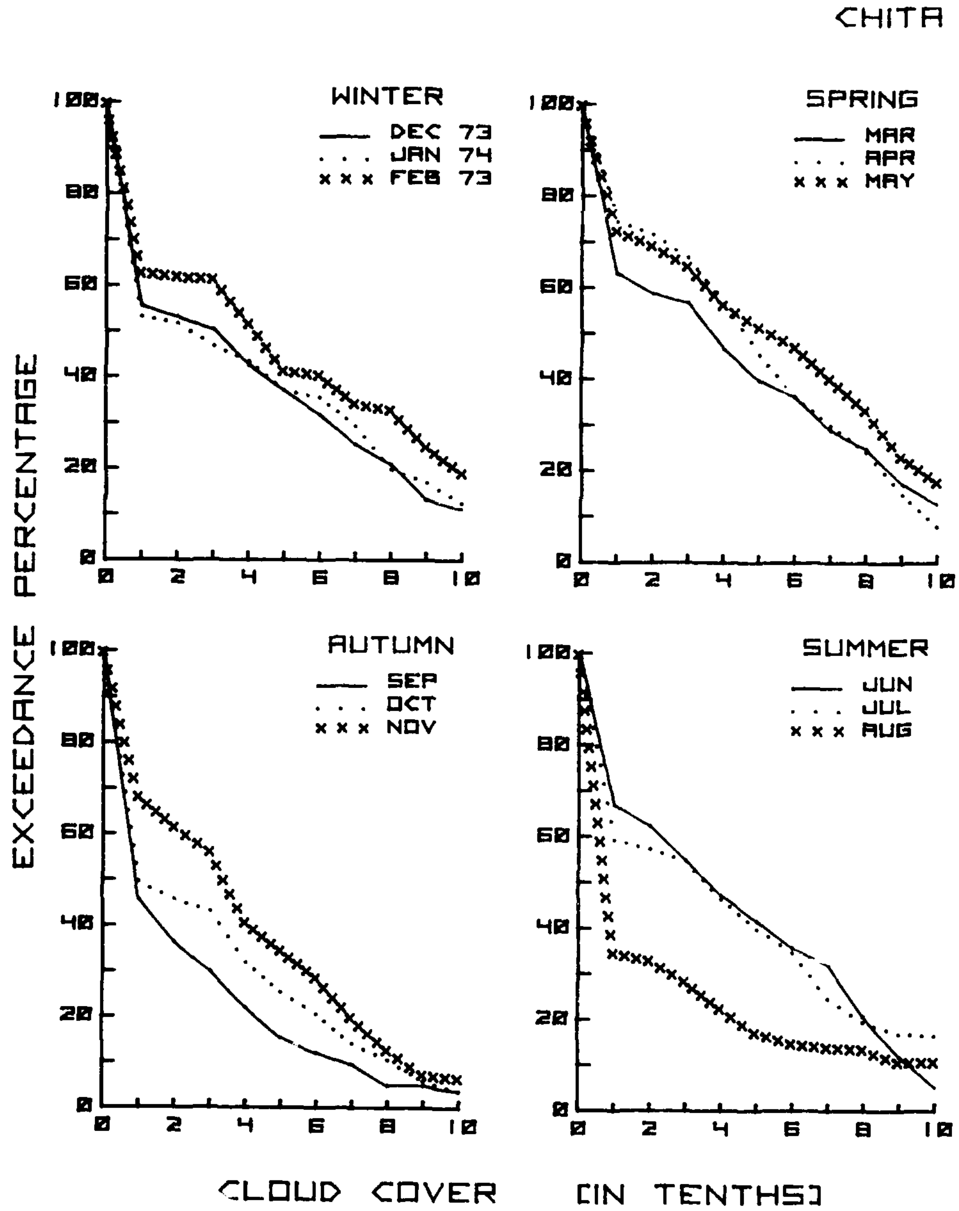

Figure 3j. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Chita

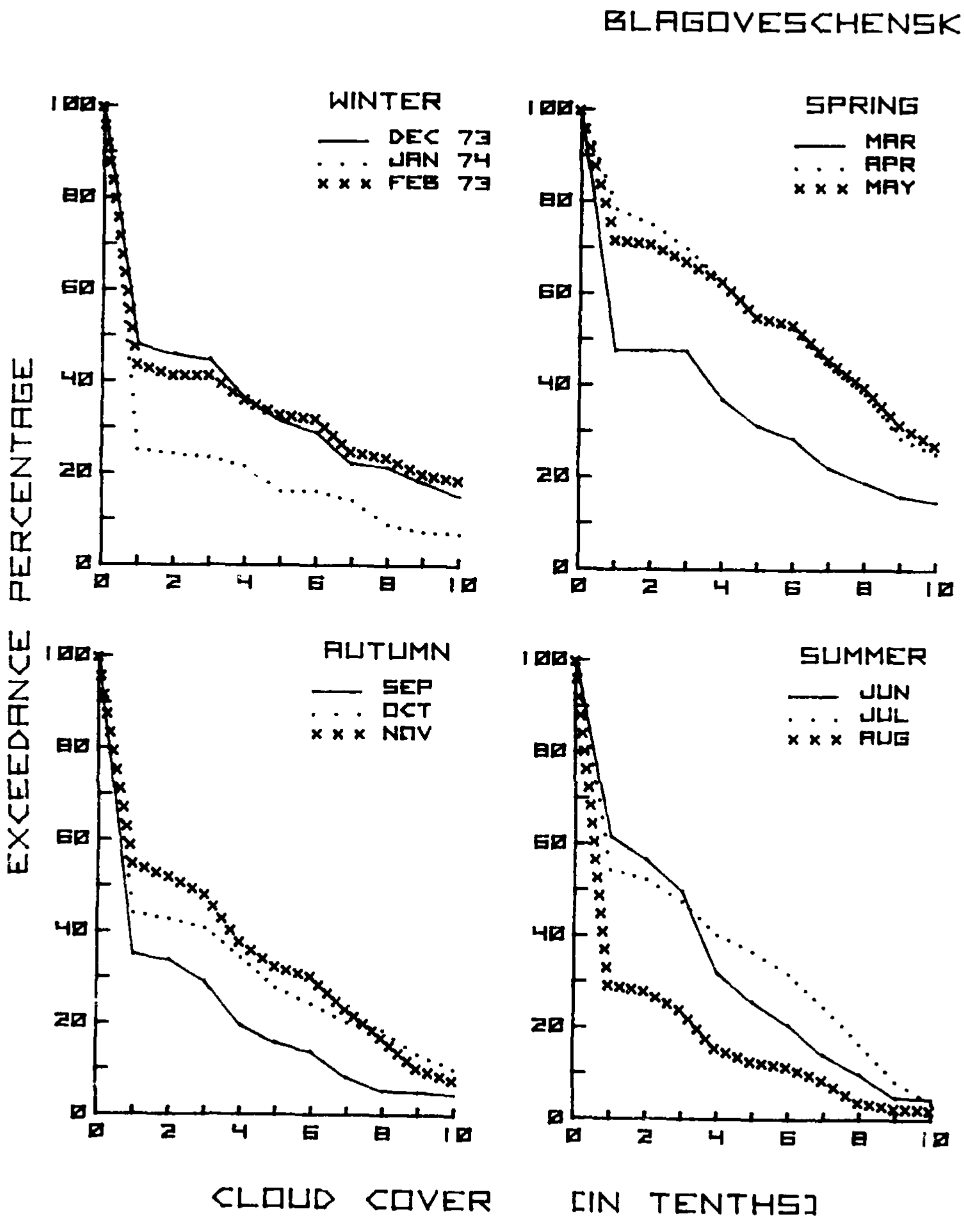

Figure 3k. Monthly Cumulative Frequency Distribution of Cirriform Cloud Occurrence by Cloud Layer Coverage for Blagoveschensk

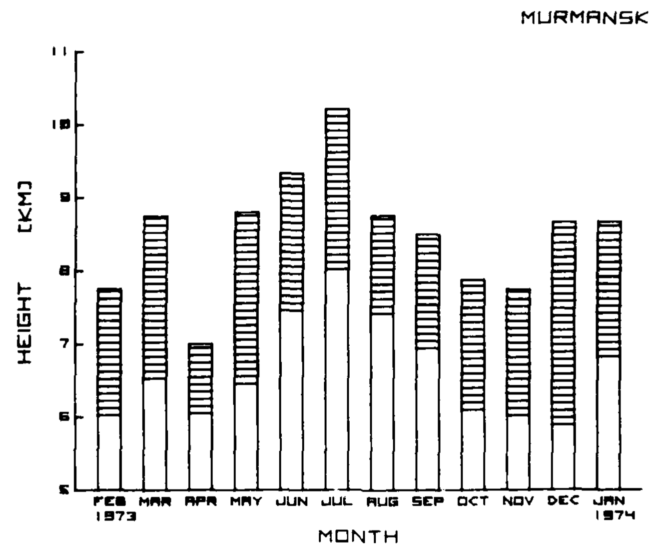

Figure 4a. Monthly Average Heights of Cirriform Cloud Tops and Bases at Murmansk

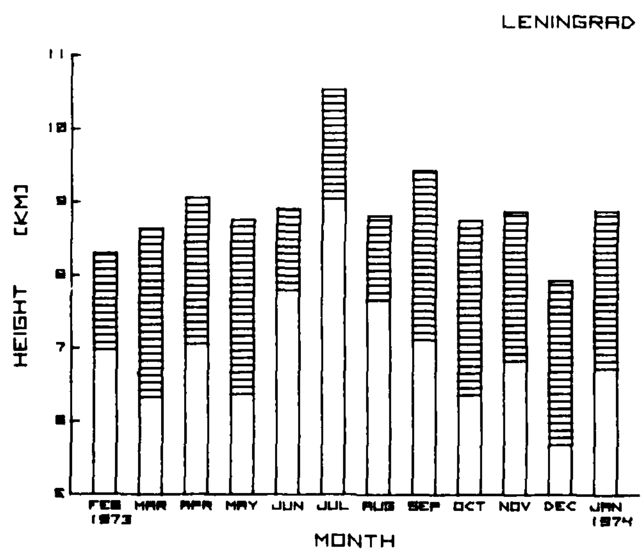

Figure 4b. Monthly Average Heights of Cirriform Cloud Tops and Bases at Leningrad

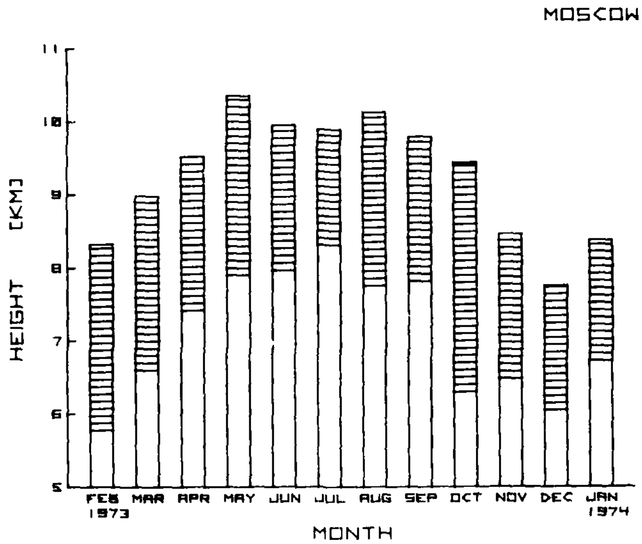

Figure 4c. Monthly Average Heights of Cirriform Cloud Tops and Bases at Moscow

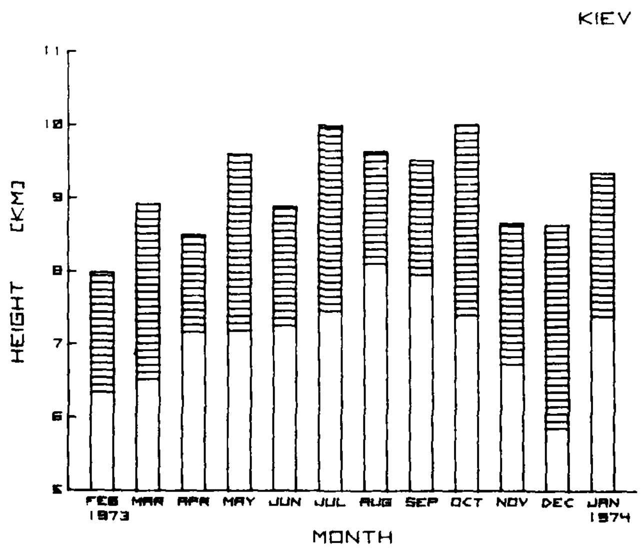

Figure 4d. Monthly Average Heights of Cirriform Cloud Tops and Bases at Kiev

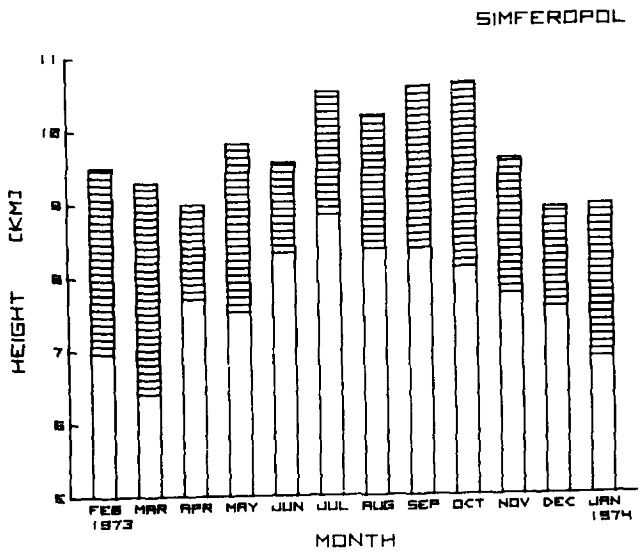

Figure 4e. Monthly Average Heights of Cirriform Cloud Tops and Bases at Simferopol

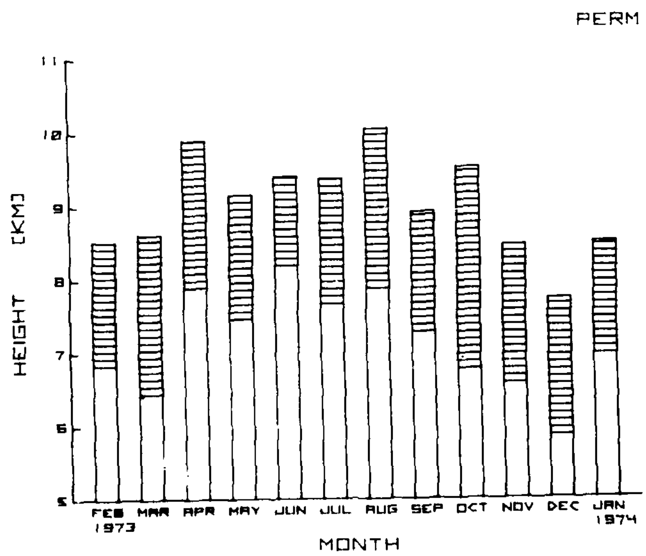

Figure 4f. Monthly Average Heights of Cirriform Cloud Tops and Bases at Perm

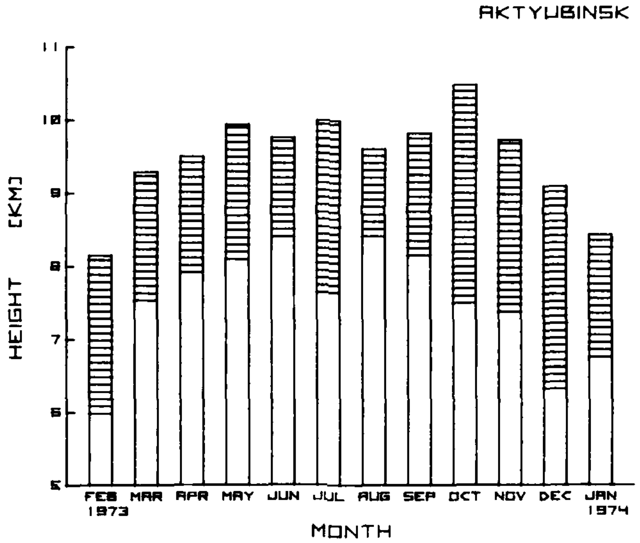

Figure 4g. Monthly Average Heights of Cirriform Cloud Tops and Bases at Aktyubinsk

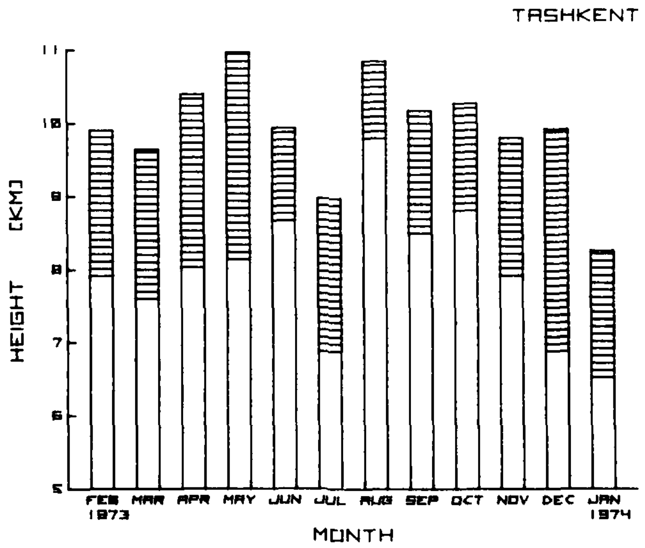

Figure 4h. Monthly Average Heights of Cirriform Cloud Tops and Bases at Tashkent

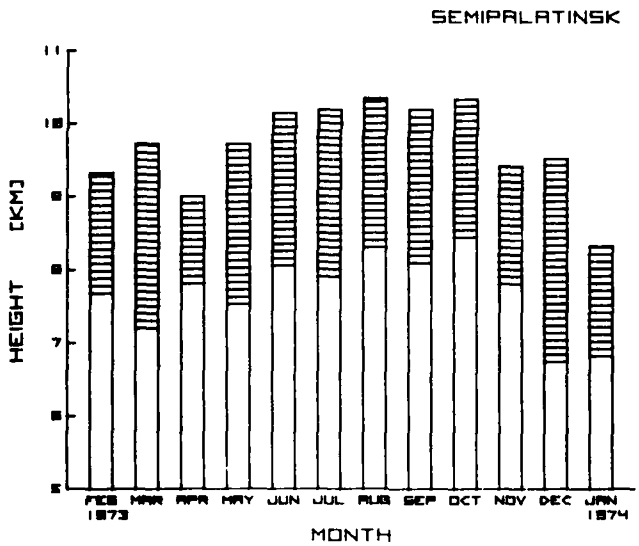

Figure 4i. Monthly Average Heights of Cirriform Cloud Tops and Bases at Semipalatinsk

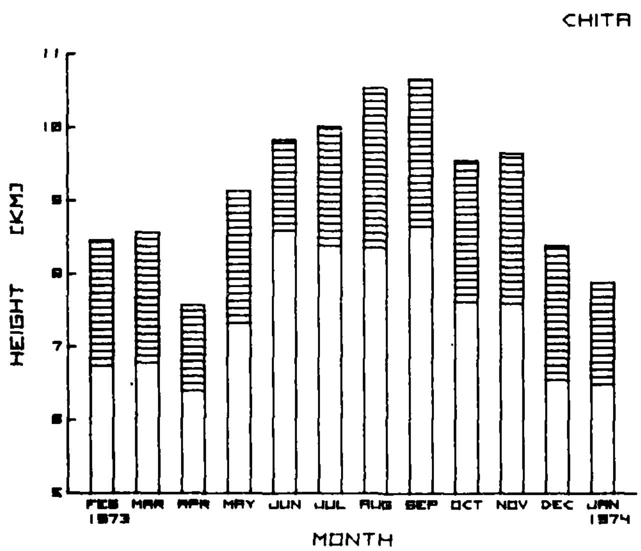

Figure 4j. Monthly Average Heights of Cirriform Cloud Tops and Bases at Chita

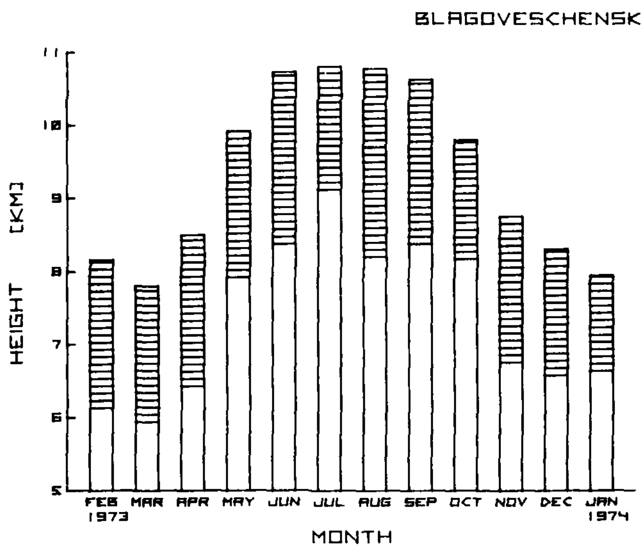

Figure 4k. Monthly Average Heights of Cirriform Cloud Tops and Bases at Blagoveschensk

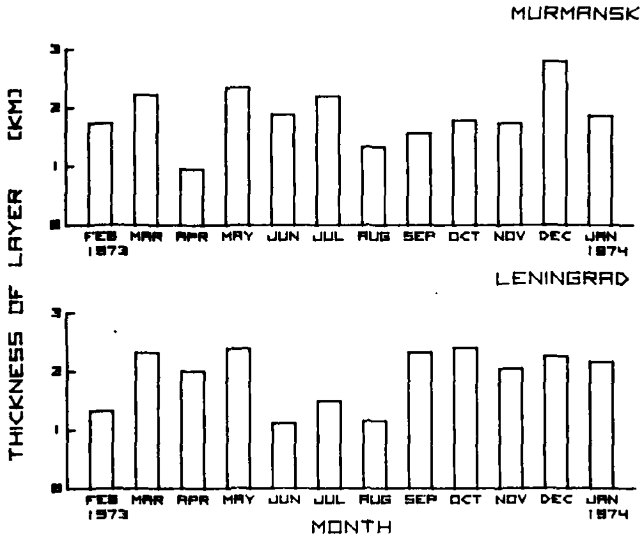

Figure 5a. Monthly Average Thickness of Cirriform Cloud Layers at Murmansk and Leningrad

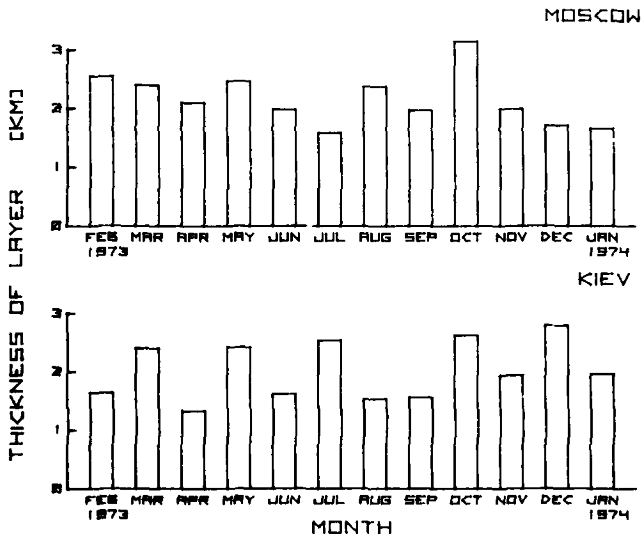

Figure 5b. Monthly Average Thickness of Cirriform Cloud Layers at Moscow and Kiev

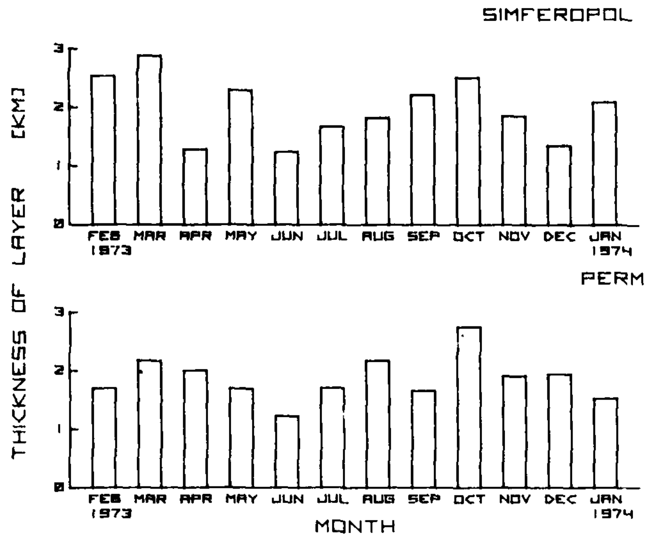

Figure 5c. Monthly Average Thickness of Cirriform Cloud Layers at Simferopol and Perm

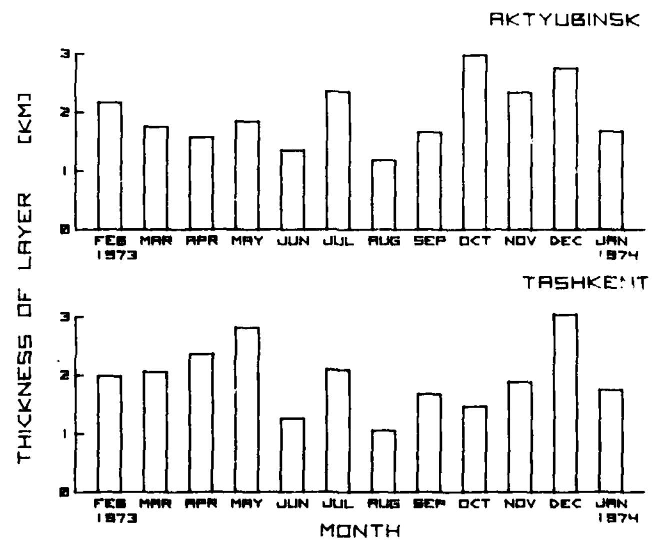

Figure 5d. Monthly Average Thickness of Cirriform Cloud Layers at Aktyubinsk and Tashkent

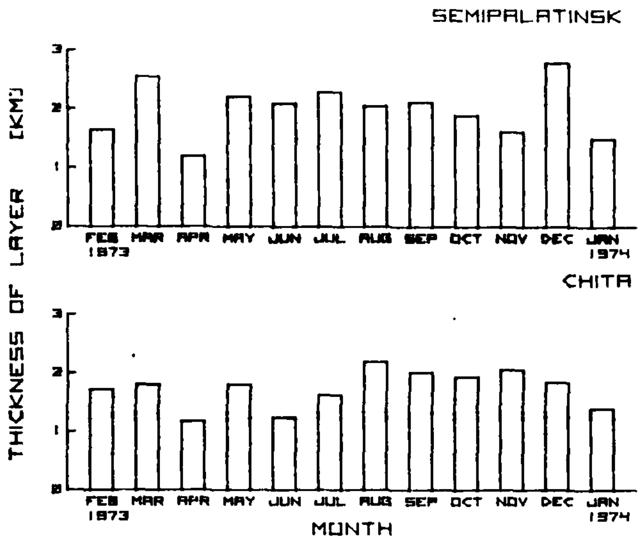

Figure 5e. Monthly Average Thickness of Cirriform Cloud Layers at Semipalatinsk and Chita

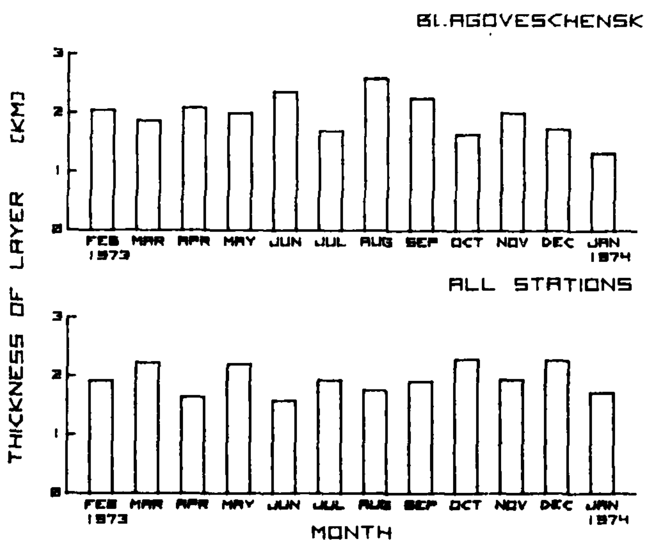

Figure 5f. Monthly Average Thickness of Cirriform Cloud Layers at Blagoveschensk and for All Stations

2.3 Liquid Water Content of Cirrus

Figures 6a through 6f show the monthly variations of the average LWC values for each station. Figure 6f also shows the averages of the monthly LWC values for the 11 stations. Like the other parameters discussed before, the month-to-month variation of LWC is not consistent. The average LWC values ranged from 0.004 g/m^3 at both Kiev and Perm in February to an extremely high value of 0.341 g/m^3 at Perm in July. The latter was greatly distorted by 13 cases of LWC values greater than or equal to 1.00 g/m^3, including one with a value of 2.00 g/m^3. Other very high monthly values are found at Semipalatinsk in July and at Tashkent in May. The cumulative frequency distributions of LWC by month (grouped by seasons) are shown in Figures 7a through 7k. The stations and months with high-valued LWC averages mentioned above are exceptionally prominent in these figures, showing the substantial contributions of the LWC values greater than 0.10 g/m^3.

A count of cirrus layers with LWC values greater than 0.10 g/m^3 yielded a total of only 135 cases. The three station-months cited above as having very high monthly averages of LWC were responsible for over 78 percent of the cases. Perm in July alone accounted for 54 percent of all the cases. The majority of the cirrus clouds with these high LWC values could be considered to be associated with or derived from cumulonimbus clouds (Cb). Of the 135 cases, 85 were presumed to be the upper cirriform part of Cb since the cirrus base and the Cb top were observed to be at the same height. An additional 10 cases were, as inferred from the recorded heights of cirrus and Cb, assumed to be cirrus clouds that became separated from the main Cb clouds. The remaining 40 cases were not Cb related and a detailed study of the individual cases is required for an explanation.

Although the role of Cb cannot be overlooked in any discussion of cirrus with large LWC values, it should be noted that not all of the cirrus that were identified with Cb were dense clouds with high LWC values. Among all the cirrus data there were 755 cases in which the cirrus bases coincided with the Cb tops. The LWC of these cirrus clouds ranged from a low of 0.005 g/m^3 to a high of 2.000 g/m^3. The average LWC of the cases was 0.105 g/m^3. The 85 cirrus of this type that were mentioned in the preceding discussion of high-valued LWC were the only ones that exceeded this average. Thus a great majority of these cirrus clouds had low to moderate values of LWC. Primarily due to the effects of the extreme values, the magnitude of the average LWC of the type of cirrus being discussed is not proportional to the number of occurrences of these cirrus clouds. For example, in July, the month that accounted for almost 31 percent of the 755 cases, 71 were observed at Perm, 67 at Chita and 33 at Semipalatinsk. The average LWC at Perm was 0.602 g/m^3. However, at Chita the average was only 0.023 g/m^3. Of interest is that at Perm 61 out of 71 cases had LWC greater than 0.10 g/m^3, at Semipalatinsk, 9 of 33, and at Chita none of 67.

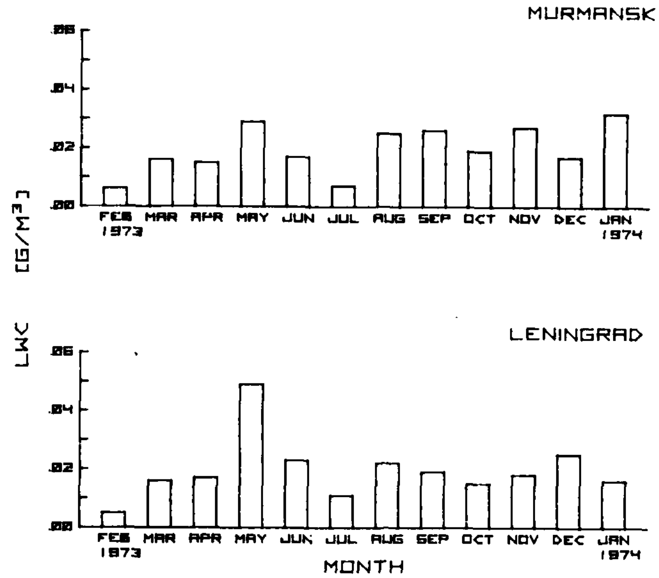

Figure 6a. Monthly Average LWC Values of Cirriform Cloud Layers at Murmansk and Leningrad

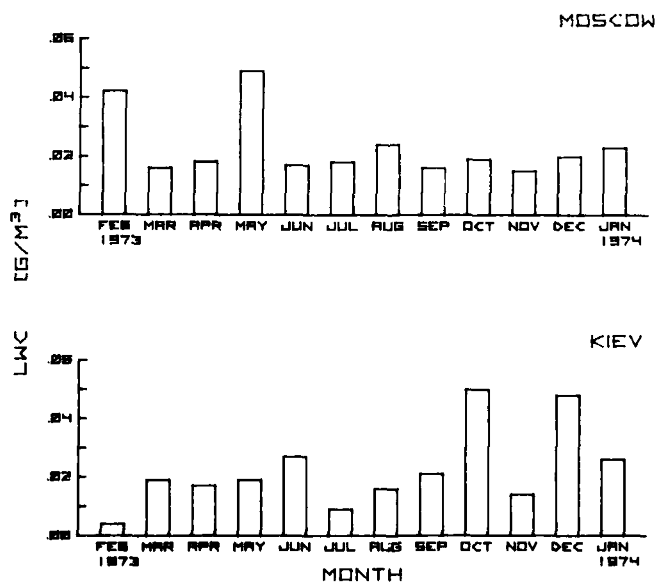

Figure 6b. Monthly Average LWC Values of Cirriform Cloud Layers at Moscow and Kiev

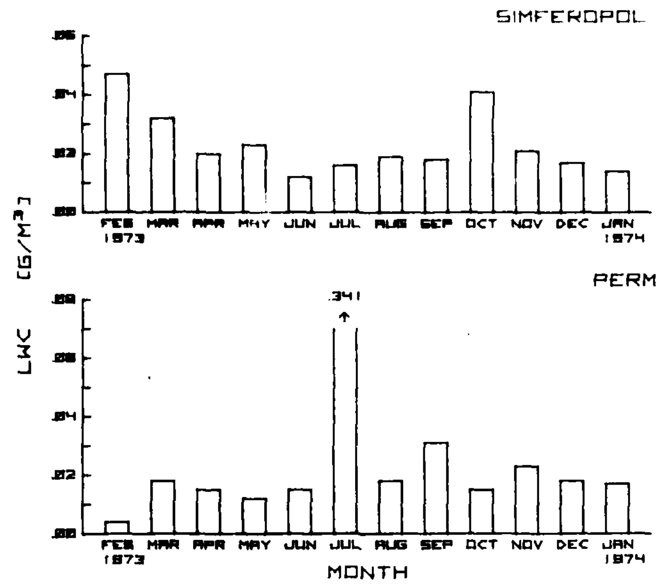

Figure 6c. Monthly Average LWC Values of Cirriform Cloud Layers at Simferopol and Perm

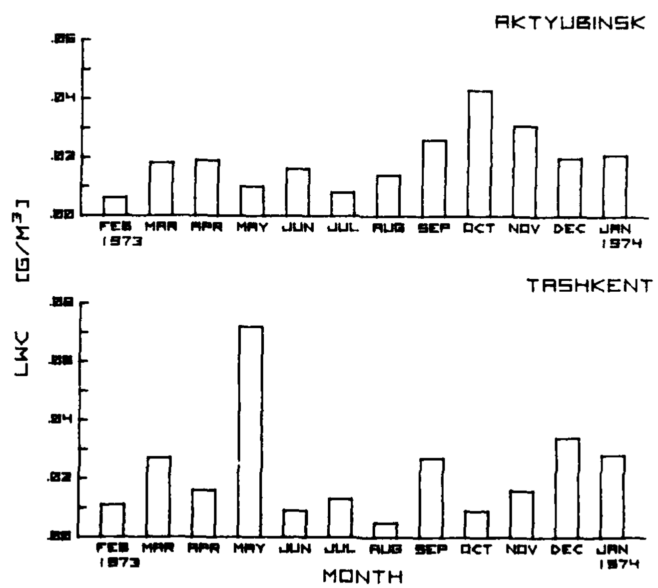

Figure 6d. Monthly Average LWC Values of Cirriform Cloud Layers at Aktyubinsk and Tashkent

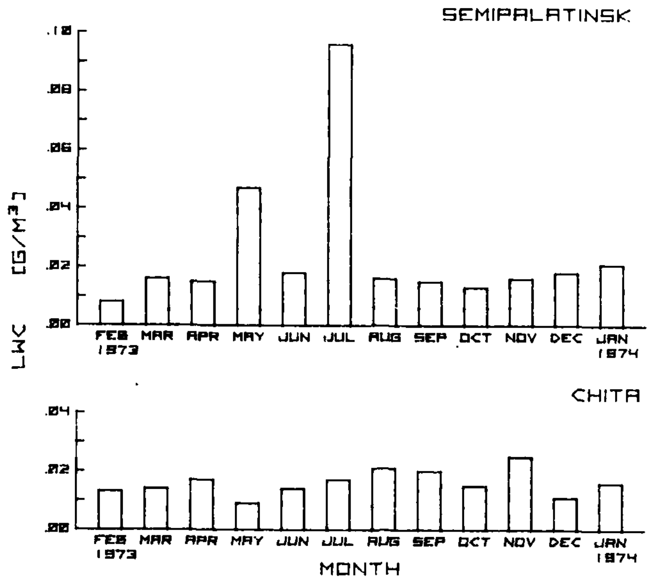

Figure 6e. Monthly Average LWC Values of Cirriform Cloud Layers at Semipalatinsk and Chita

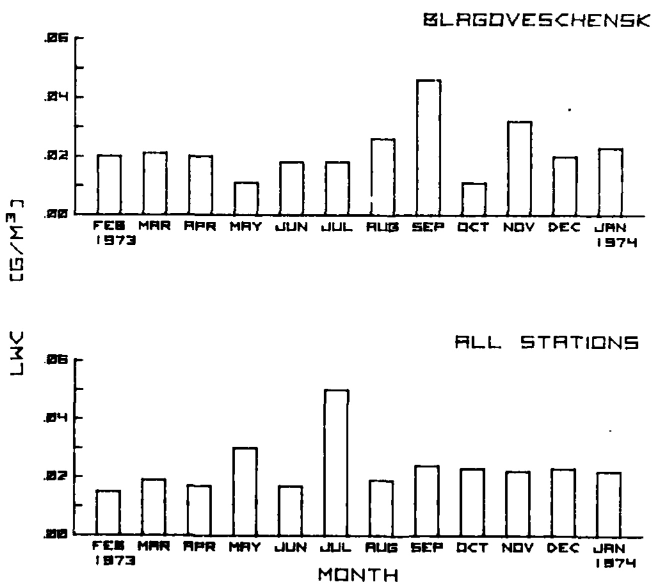

Figure 6f. Monthly Average LWC Values of Cirriform Cloud Layers at Blagoveschensk and for All Stations

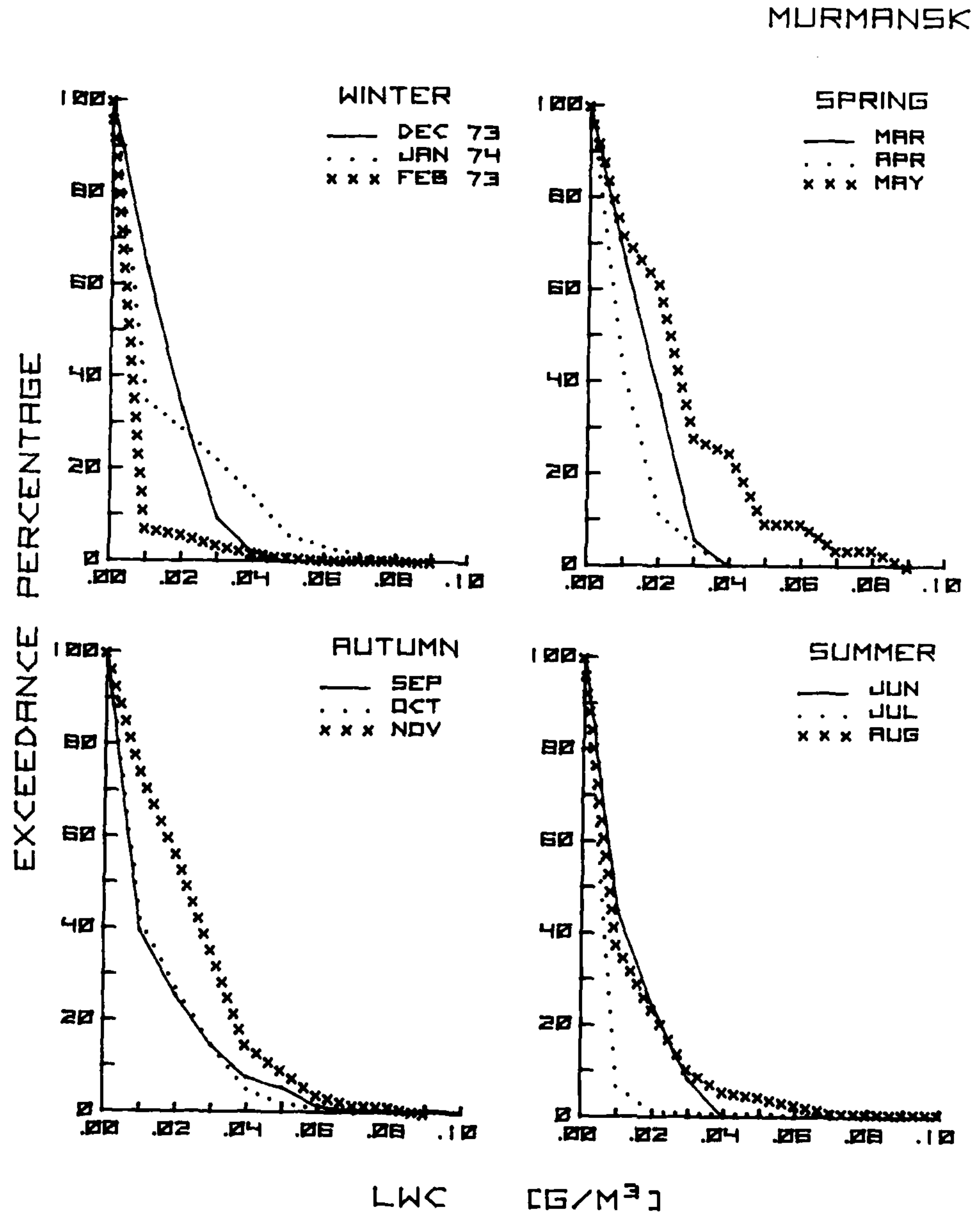

Figure 7a. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Murmansk

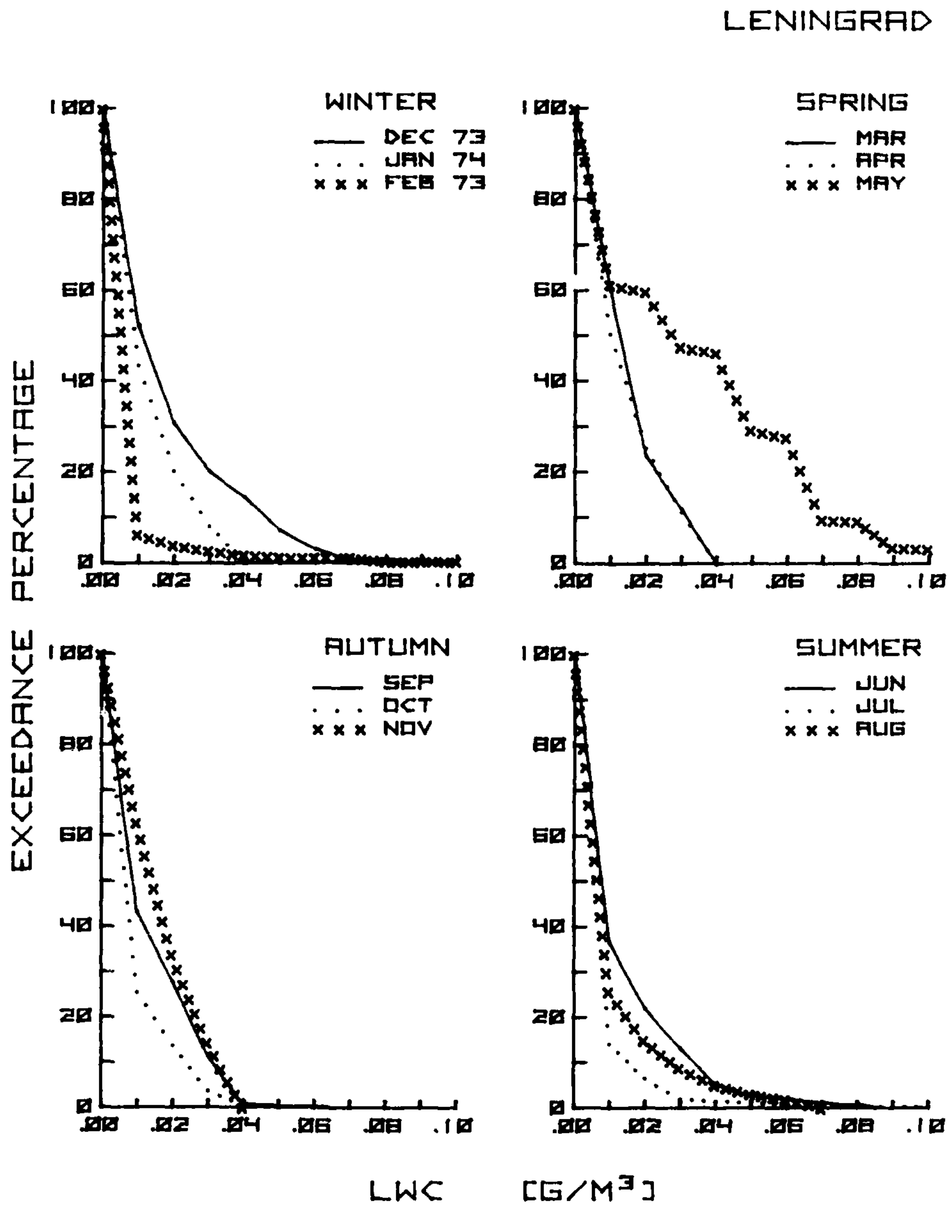

Figure 7b. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Leningrad

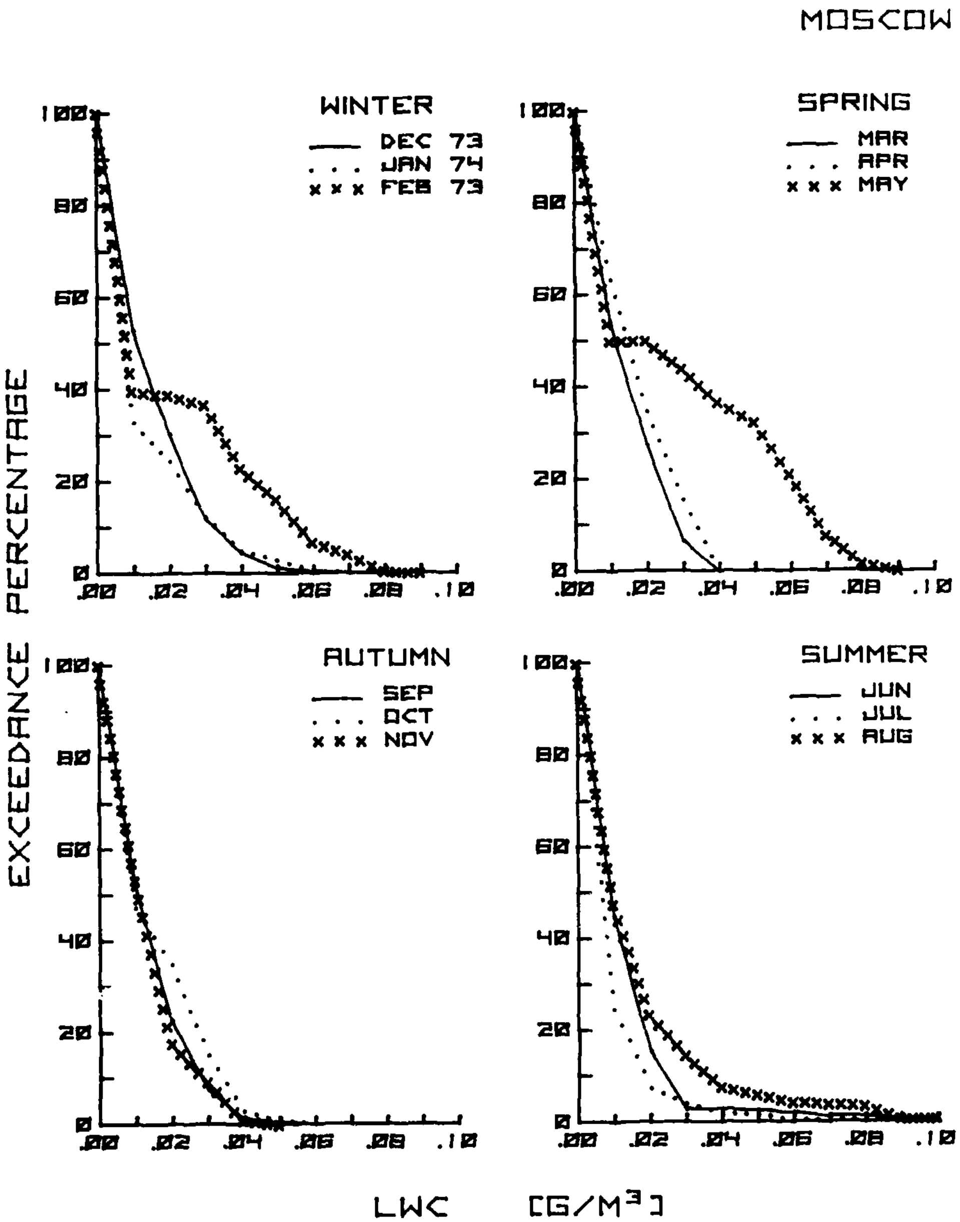

Figure 7c. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Moscow

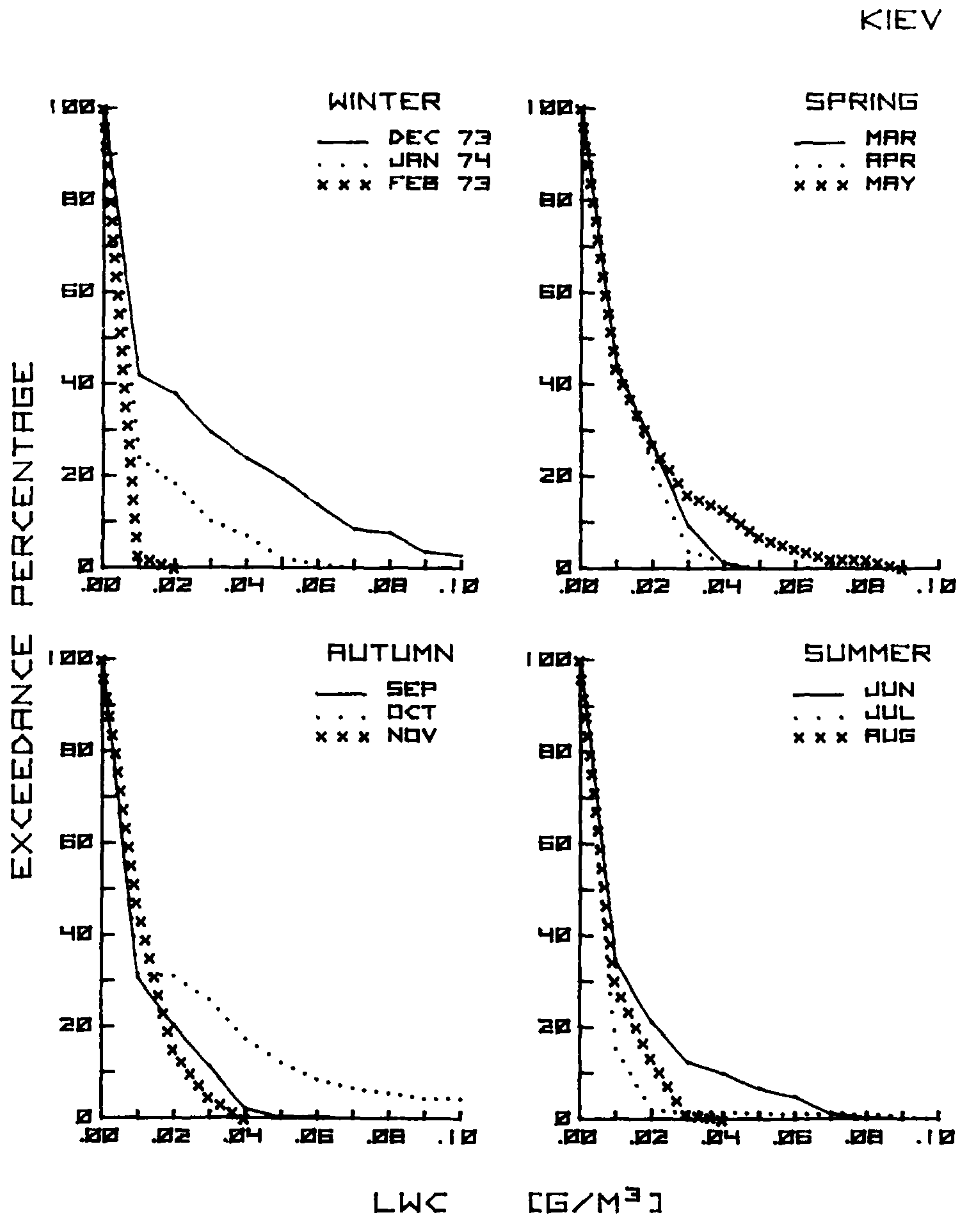

Figure 7d. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Kiev

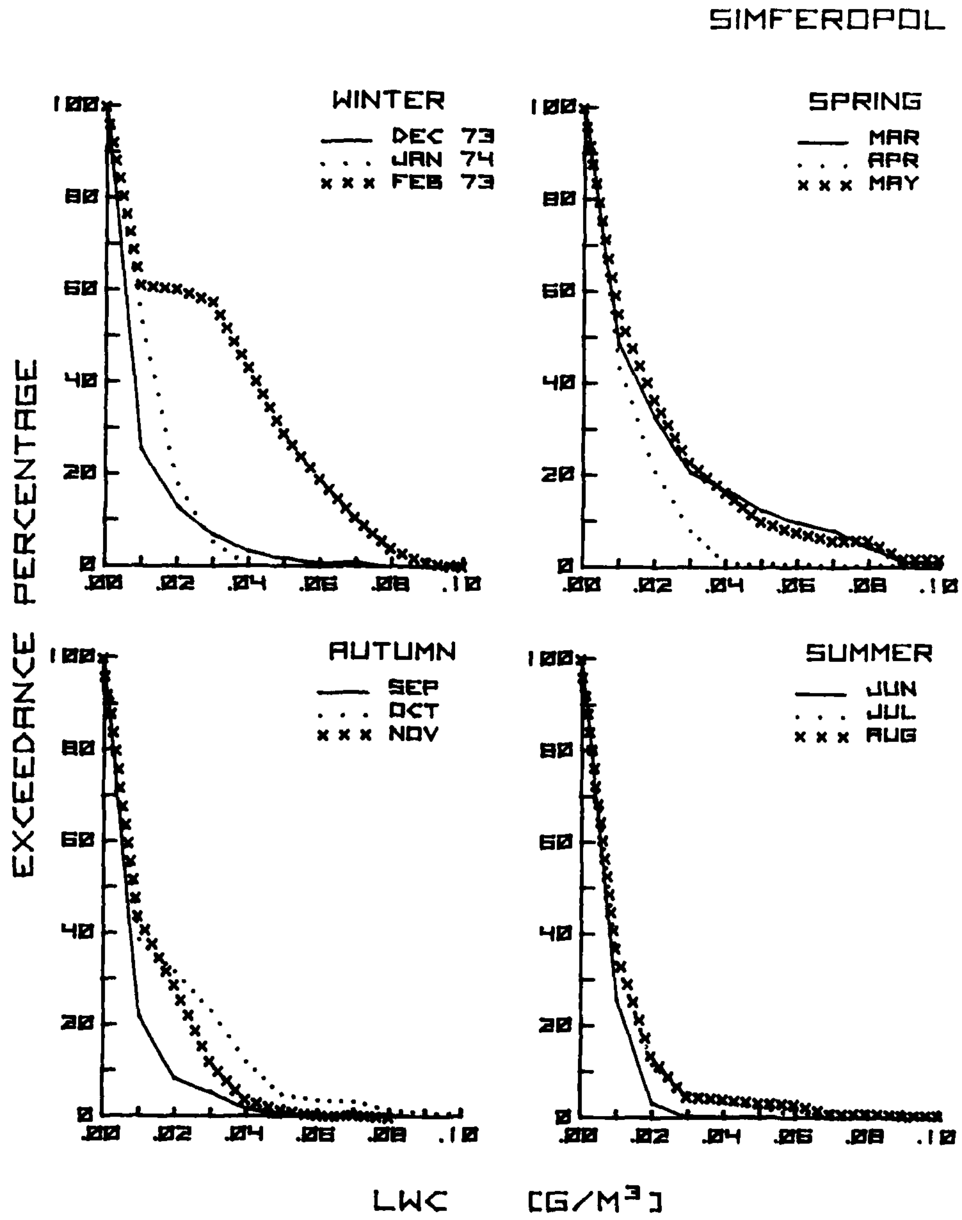

Figure 7e. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Simferopol

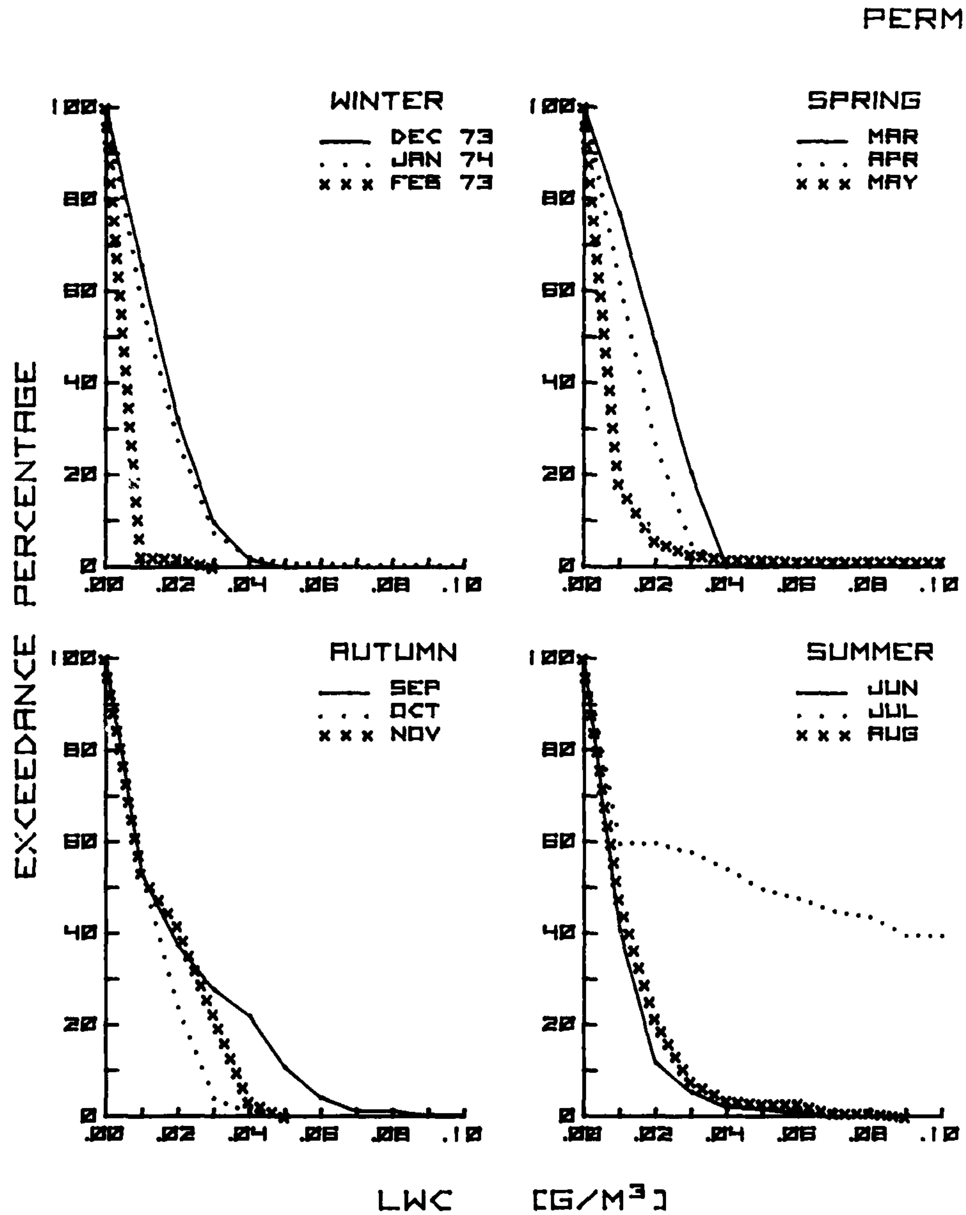

Figure 7f. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Perm

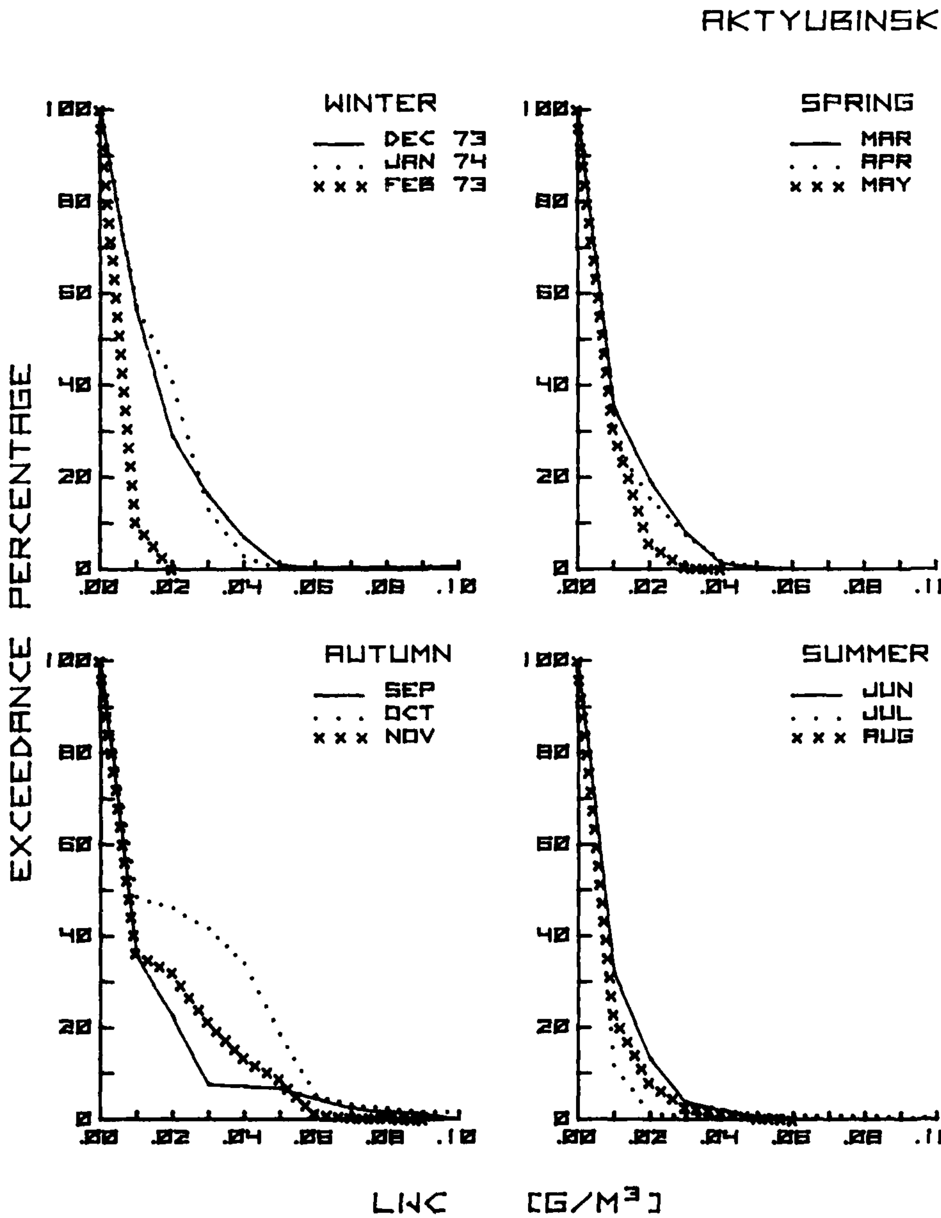

Figure 7g. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Aktyubinsk

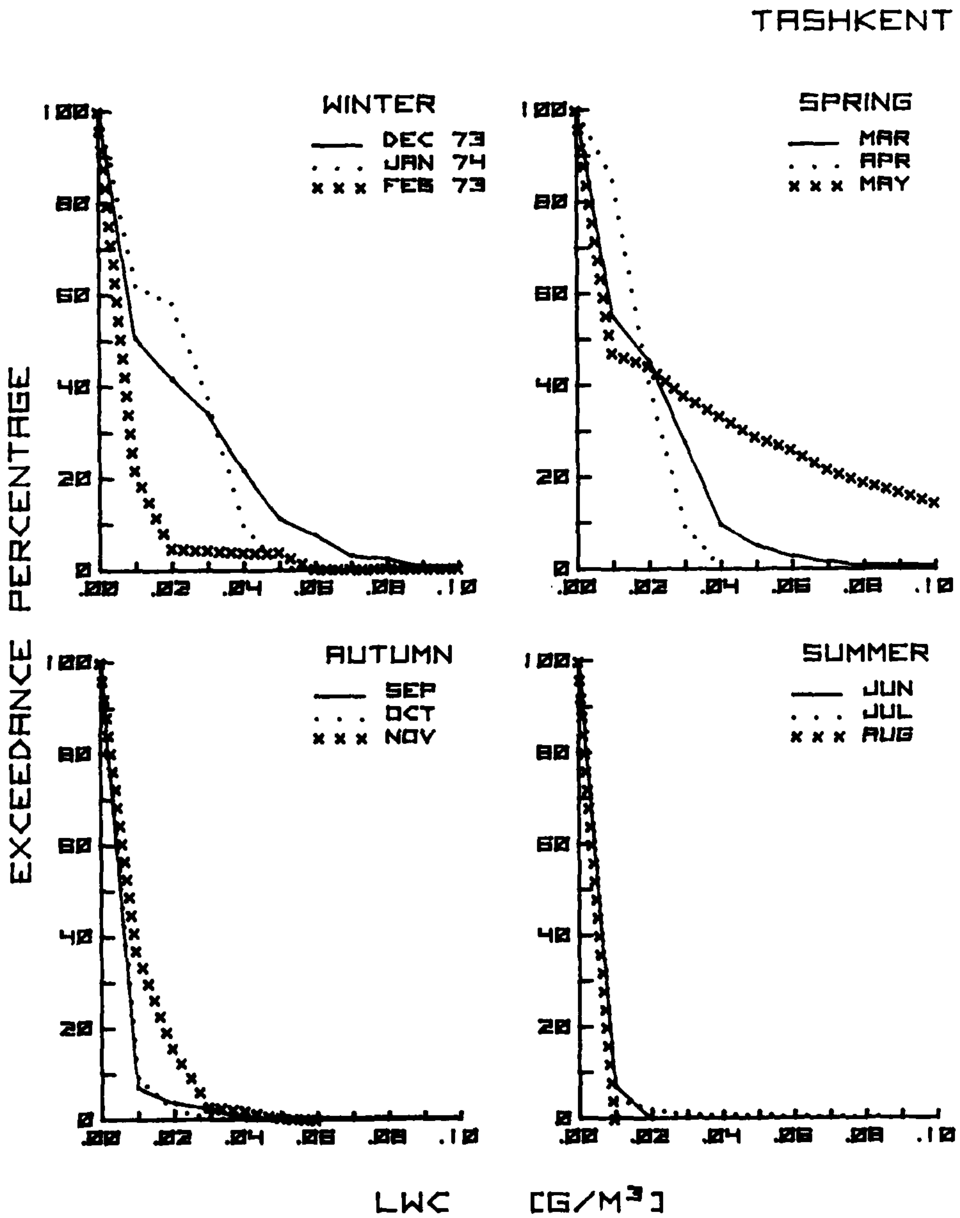

Figure 7h. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Tashkent

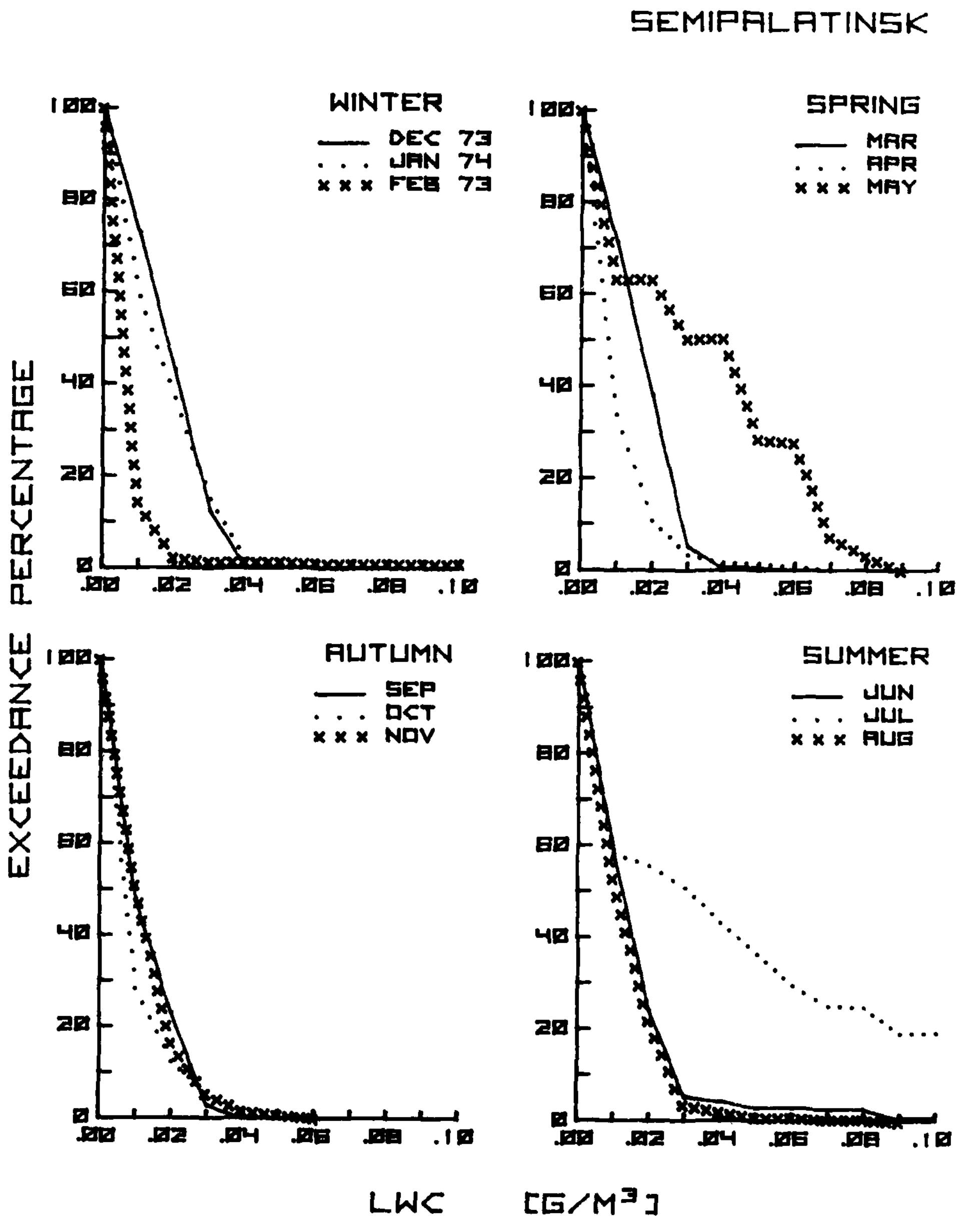

Figure 7i. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Semipalatinsk

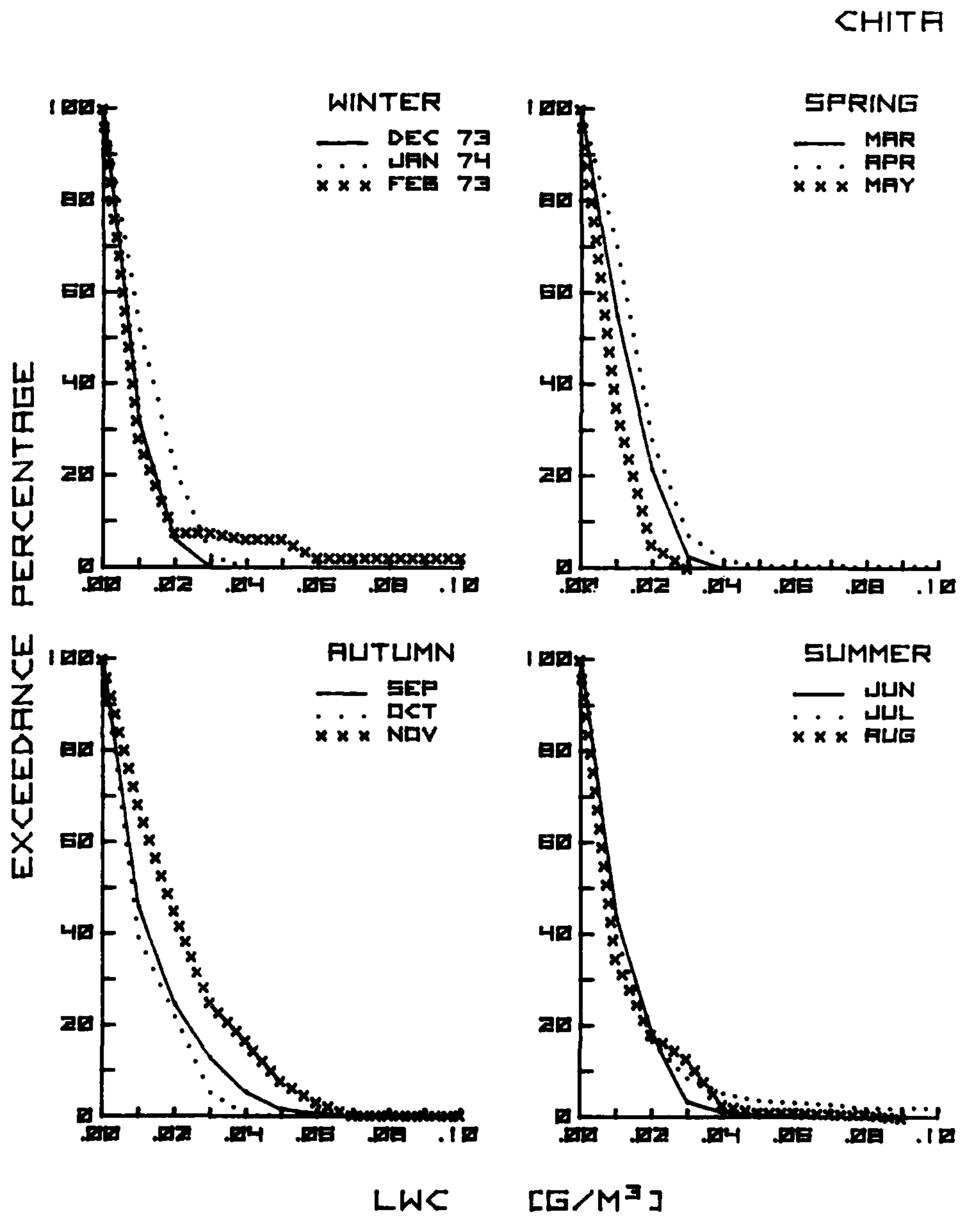

Figure 7j. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Chita

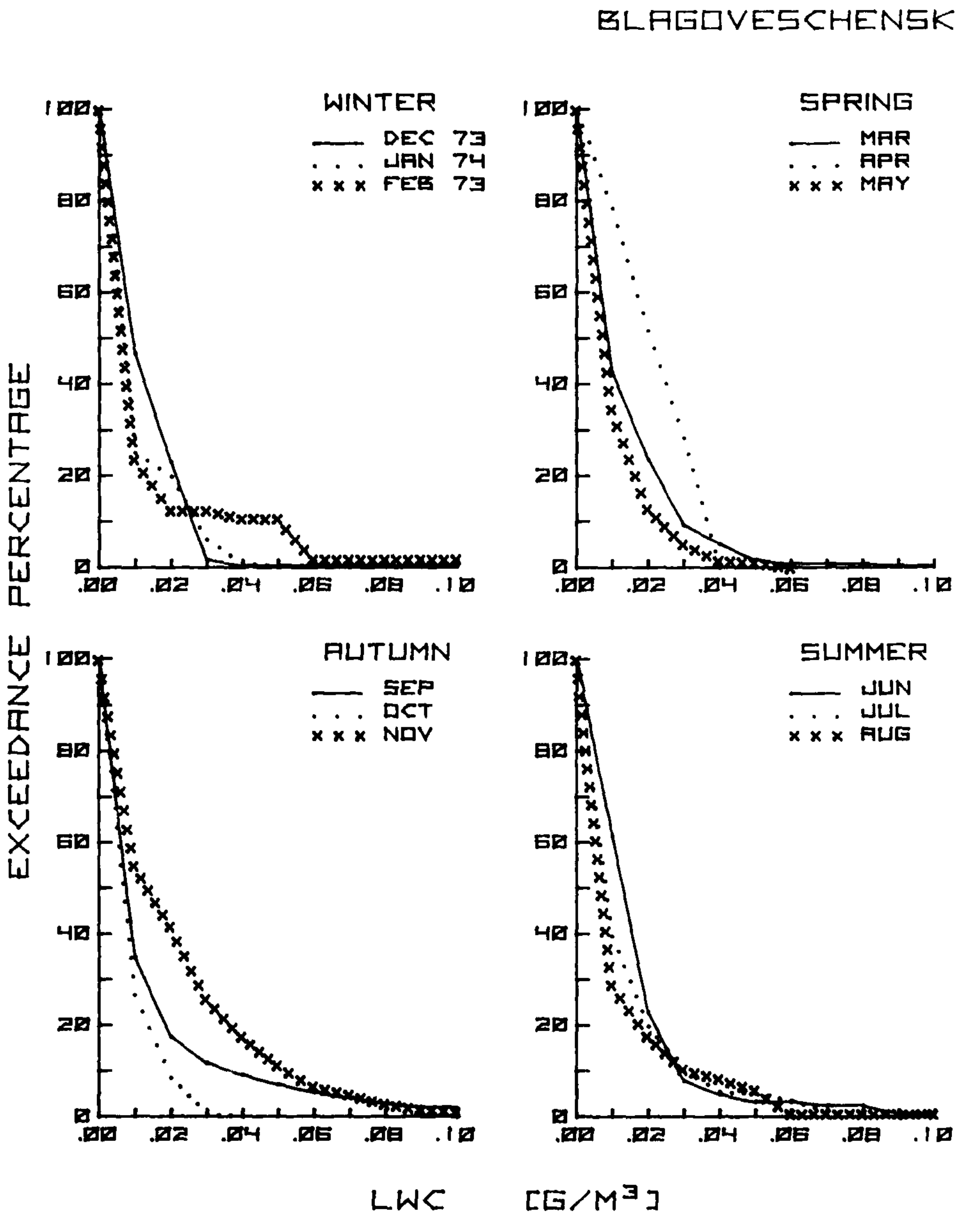

Figure 7k. Monthly Cumulative Frequency Distribution of Cirriform Cloud LWC for Blagoveschensk

3. CIRRIFORM CLOUD STUDY BY SEASONS

The monthly statistics of cirrus clouds indicated seasonal and, at times, geographical variations in the frequencies, heights, thicknesses, and LWC of the high clouds. However, the month-to-month variabilities of these parameters were usually so erratic that the seasonal and geographical effects could not be determined with any certainty. Only the extreme features and conspicuous exceptions associated with a particular station and with a particular month could be cited with any certainty. For this reason the data will be presented by seasons—winter (December 1973, January 1974, and February 1973), spring (March, April, and May 1973), summer (June, July, and August 1973), and autumn (September, October and November 1973).

3.1 Frequency of Cirrus

Figure 8 shows the percentage frequency of occurrence of cirrus by season for each of the 11 stations and for all stations combined (striped bars). The seasonal mean frequencies for all 11 stations show cirrus to be most frequent in spring and least frequent in summer. The seasonal mean frequencies of occurrence were 58.9 percent in spring and 53.6 percent in winter, dropping to 45.5 percent in autumn and 43.9 percent in summer. The frequencies of occurrence at the individual stations varied from as high as 70.1 percent at Chita in spring to as low as 8.6 percent at Tashkent in summer. Four stations—Murmansk, Perm, Semipalatinsk, and Chita—show frequencies higher than the 11-station seasonal means for all four seasons. On the other hand, two stations—Kiev and Simferopol—show frequencies lower than the 11-station seasonal means for all seasons. The remaining stations all display frequencies that are above the seasonal means in two seasons and below in two seasons. The map in Figure 1 shows the locations of the stations used to illustrate the geographical variation of the frequency of cirrus. If Blagoveschensk is excluded, the four high-frequency stations for all seasons lie along the northeastern perimeter of the 11 stations, and the two low-frequency stations, although only a short distance apart, form the southwestern perimeter. The other stations, with the exception of Blagoveschensk, fall between the two sets of stations. Thus, it can be stated that, within the domain of the 11 stations, there were meaningful seasonal and geographical variations in the frequency of cirrus clouds during the 12-month period.

Table 3 lists the frequency distribution of cirrus occurrences by cloud cover (in tenths) based on all the cirrus data. The table is presented to show the irregularities in the cirrus cloud cover distribution. Whether the double-digit percentage figures for 3/10th cloud cover and for the larger even-numbered cloud coverages

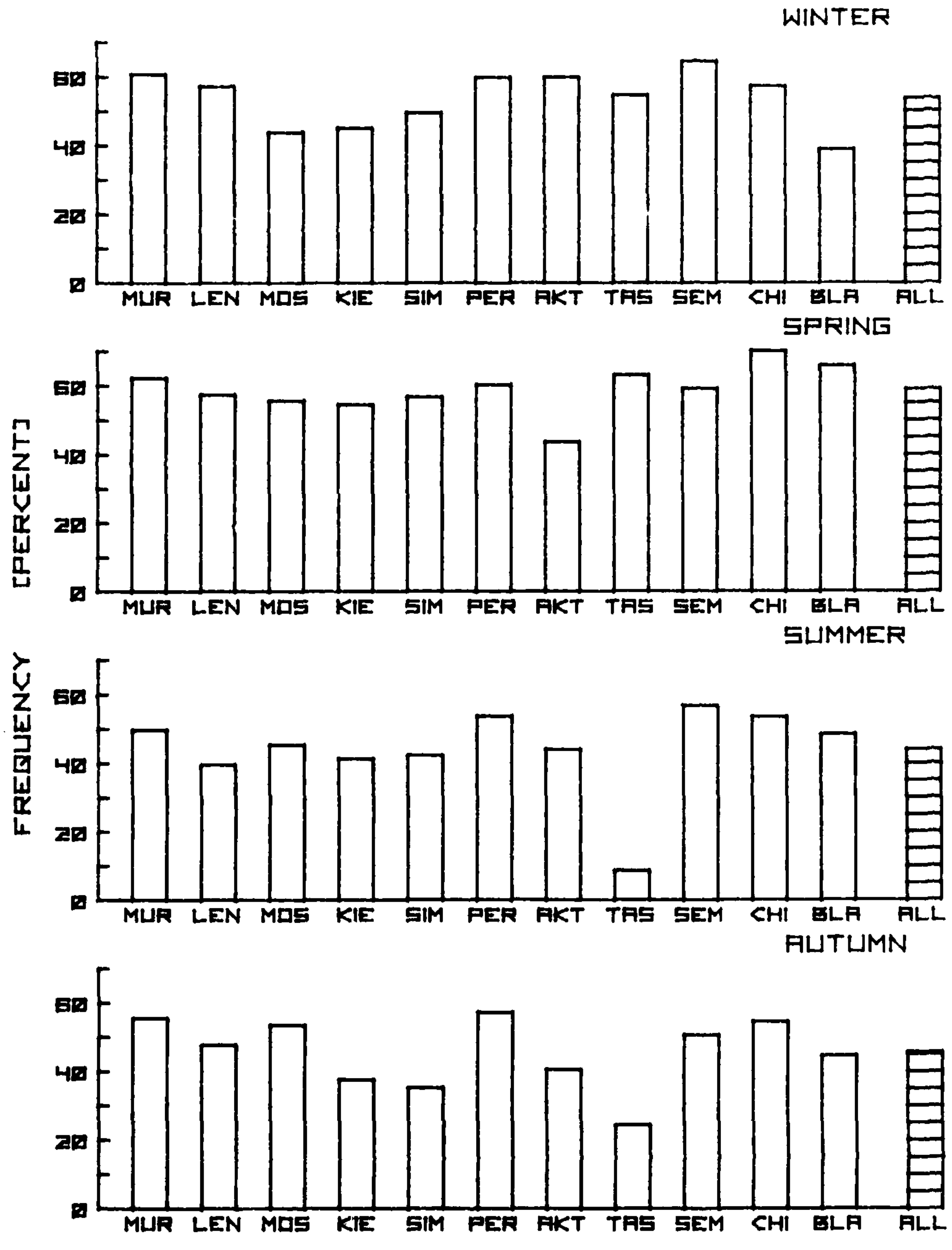

Figure 8. Seasonal Percentage Frequency of Cirriform Cloud Occurrence

are real, or due to the preferences of USSR ground observers or the AFGL-2 analysts in estimating the cirrus layer coverage, cannot be said. To avoid the irregularities, the cirrus layer coverage classifications of clear (no cirrus), scatter (1/10th through 5/10th), broken (6/10th through 9/10th) and overcast (10/10th) were used. Figures 9a, 9b, and 9c show the seasonal frequency of occurrence by cloud cover for each station and for all stations combined. It is quite evident that, in the majority of the cases, the frequency of occurrence decreases with increasing cloudiness under this broad cloud cover classification.

Table 3. Percentage Frequency of Cirriform Clouds by Cloud Cover

Cloud Cover (in tenths)	Percent
1	8.1
2	8.3
3	14.8
4	10.9
5	7.1
6	11.6
7	8.4
8	10.6
9	7.3
10	13.0

3.2 Cirrus Top and Base Heights

The seasonal average top and base heights and the associated thickness (horizontally striped) of the cirrus layer for the individual stations and for all stations combined (horizontal and vertical stripes) are presented in Figure 10. The seasonal mean top and base heights for the 11 stations are highest in summer and lowest in winter. The mean top and base heights for the seasons were 9.9 and 8.1 km in summer, 9.4 and 7.3 km in autumn, 9.2 and 7.1 km in spring, and 8.5 and 6.6 km in winter. The average top height for the individual stations ranged from 8.0 km at Murmansk in autumn to 10.8 km at Blagoveschensk in summer. The average base height varied from 6.1 km at Murmansk in winter to 8.6 km at Blagoveschensk in summer.

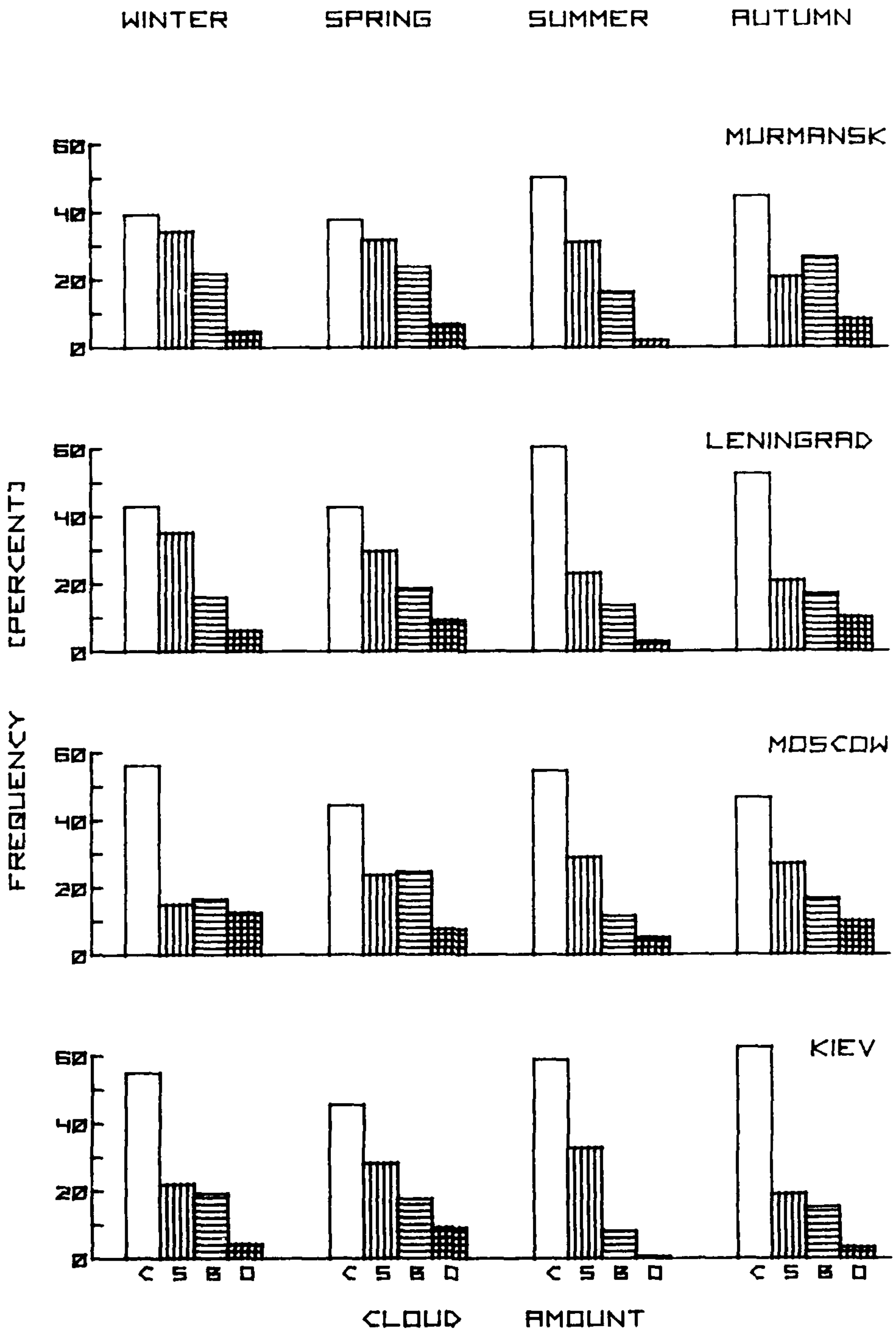

Figure 9a. Seasonal Frequency of Cirriform Cloud Occurrence by Cloud Cover for Murmansk, Leningrad, Moscow, and Kiev. (c - clear bar for clear and no cirrus; s - vertically striped bar for scatter; b - horizontally striped bar for broken; and o - vertically and horizontally striped bar for overcast)

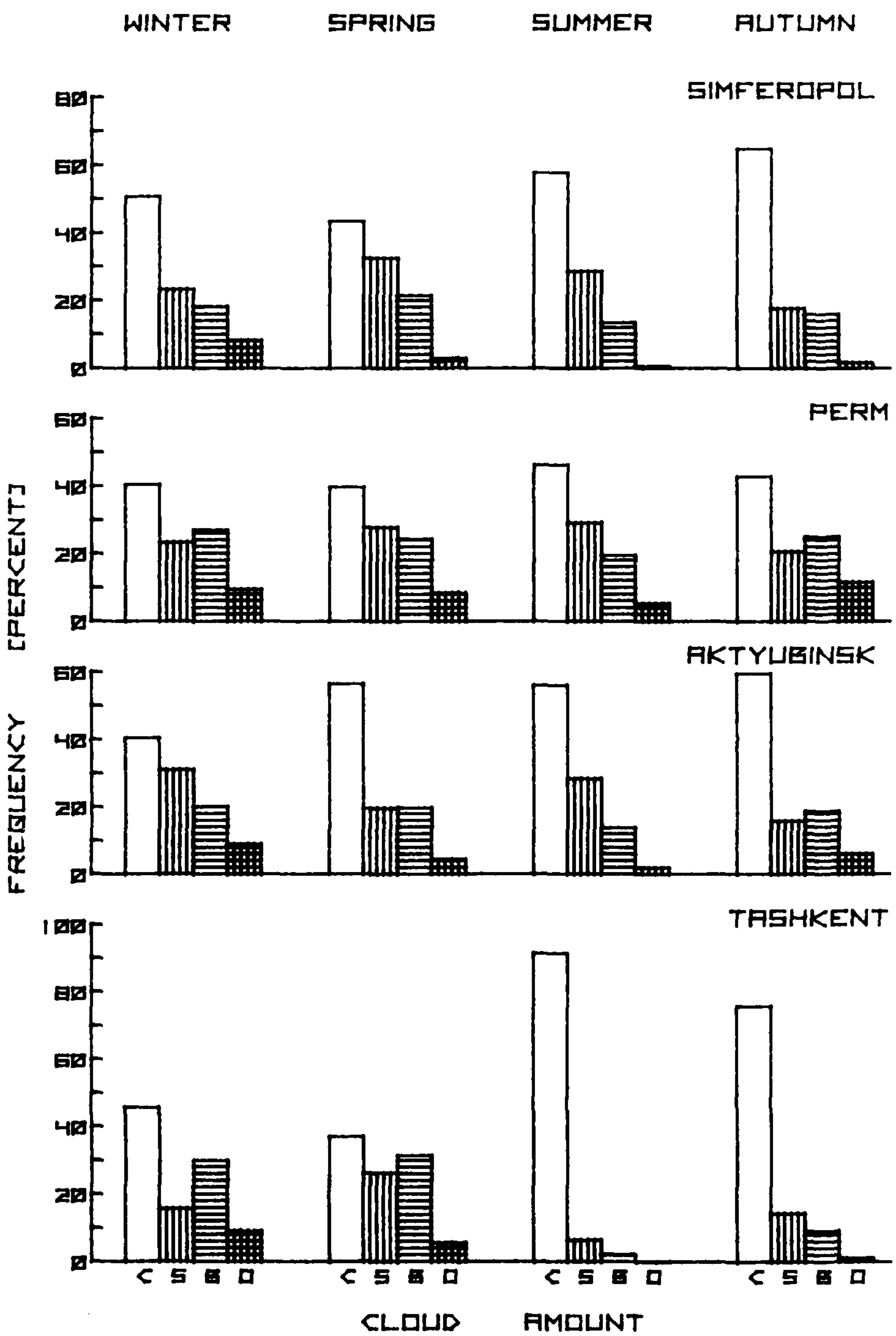

Figure 9b. Seasonal Frequency of Cirriform Cloud Occurrence by Cloud Cover for Simferopol, Perm, Aktyubinsk, and Tashkent

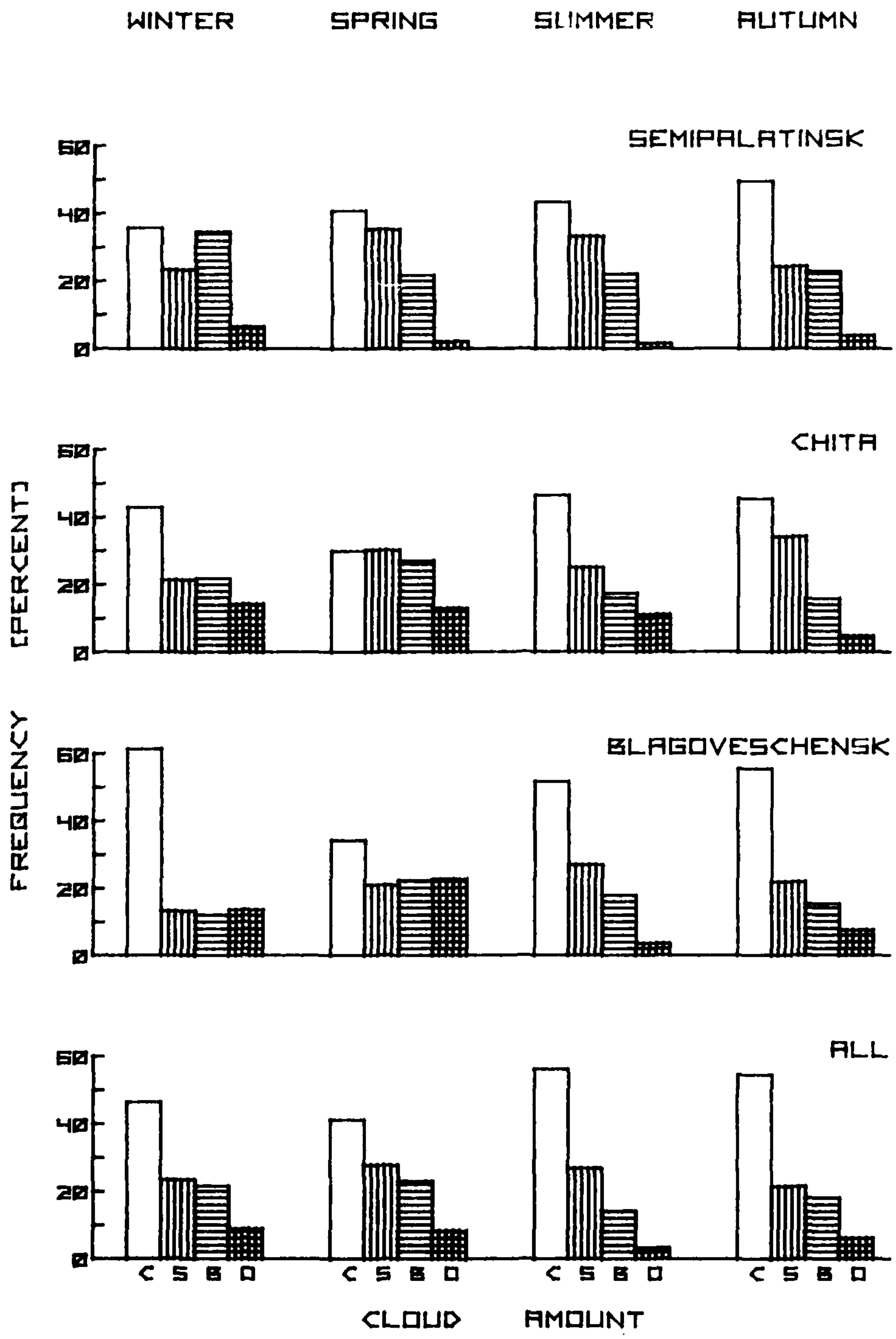

Figure 9c. Seasonal Frequency of Cirriform Cloud Occurrence by Cloud Cover for Semipalatinsk, Chita, Blagoveschensk, and for All Stations

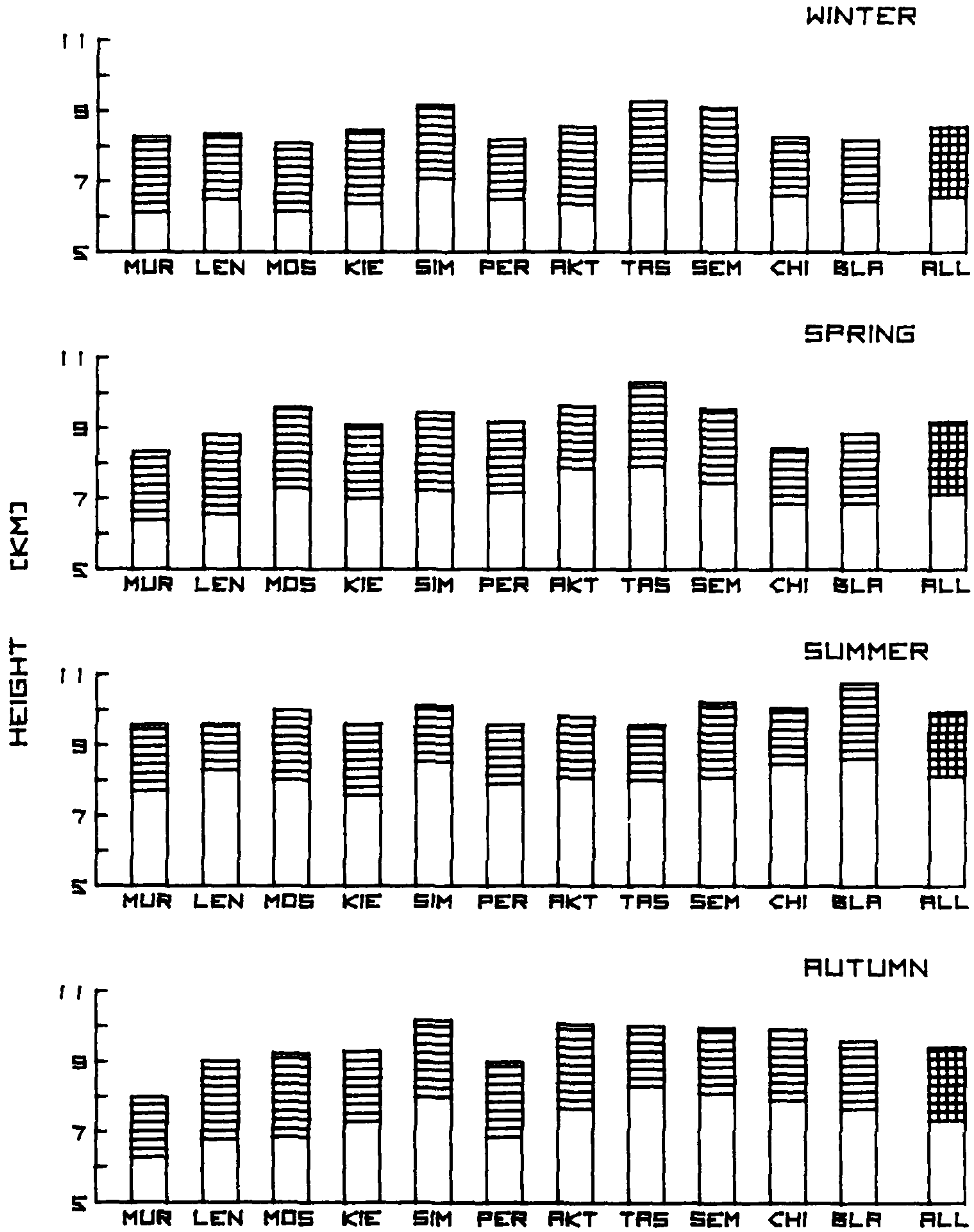

Figure 10. Seasonal Average Top and Base Heights of Cirriform Cloud Layers

Figures 11a, 11b, and 11c show the seasonal variation of the top and base heights of cirrus layers by the cloud amount of scatter, broken, and overcast. They show that the height variations of cirrus top within a season is small and top height is not a function of the amount of cloud cover. The height variation of the cirrus base, however, is shown to be greater and, in the majority of the cases, the base height decreases with increasing cloudiness. Thus, the scattered clouds have higher bases and are consequently thinner than the broken and overcast clouds. The figures also show that for any cloud cover amount the cirrus top and base are usually the highest in summer and the lowest in winter.

Figures 12a through 12k show the seasonal frequency distribution of the heights of cirrus tops and Figures 13a through 13k the frequency distribution of the heights of cirrus bases at 1,000-ft intervals for each station. Since the height analyses of cirrus layers were originally made in thousands of feet, the abscissas in all these figures are purposely scaled in feet rather than in kilometers to illustrate another irregularity of the data. As can be seen in many of the distribution plots the rise at height intervals of even thousands of feet and the fall at height interval of odd thousands of feet are most likely to be due to the cross-section analysts' preferences for estimating the top and base heights to the nearest 2000 ft. Despite the distractions from the up and down irregularities, the seasonal shifts, particularly of the heights of maximum frequencies for both top and base are notable for most of the stations. The heights of the maximum frequencies for the top are generally the highest in summer and autumn and lowest in winter. The heights of the maximum frequencies for the cloud base are generally highest in the summer and lowest in winter. The height of the cloud top extended from 13,000 ft to 46,000 ft and the base from 9000 ft to 39,000 ft. The greatest range of heights for both the top and base are found in autumn and winter and the smallest range in summer.

The frequency distributions of the top and base heights for all stations combined are shown in Figures 14a and 14b, respectively. The height interval is expanded to 2000 ft to smooth out the irregularities displayed in the previous figures. Plotted in this manner, the marked difference of the summer distribution for the top and base from the other seasons becomes quite evident.

3.3 Cirrus Thickness

The average thicknesses of cirrus layers for the individual stations and for all stations combined are shown by seasons in Figure 15. The thickness varied from 1.3 km at Leningrad in summer to a high of 2.4 km at Aktyubinsk in autumn. The seasonal mean thicknesses for all the stations were 2.1 km in autumn and spring, 2.0 km in winter, and 1.8 km in summer.

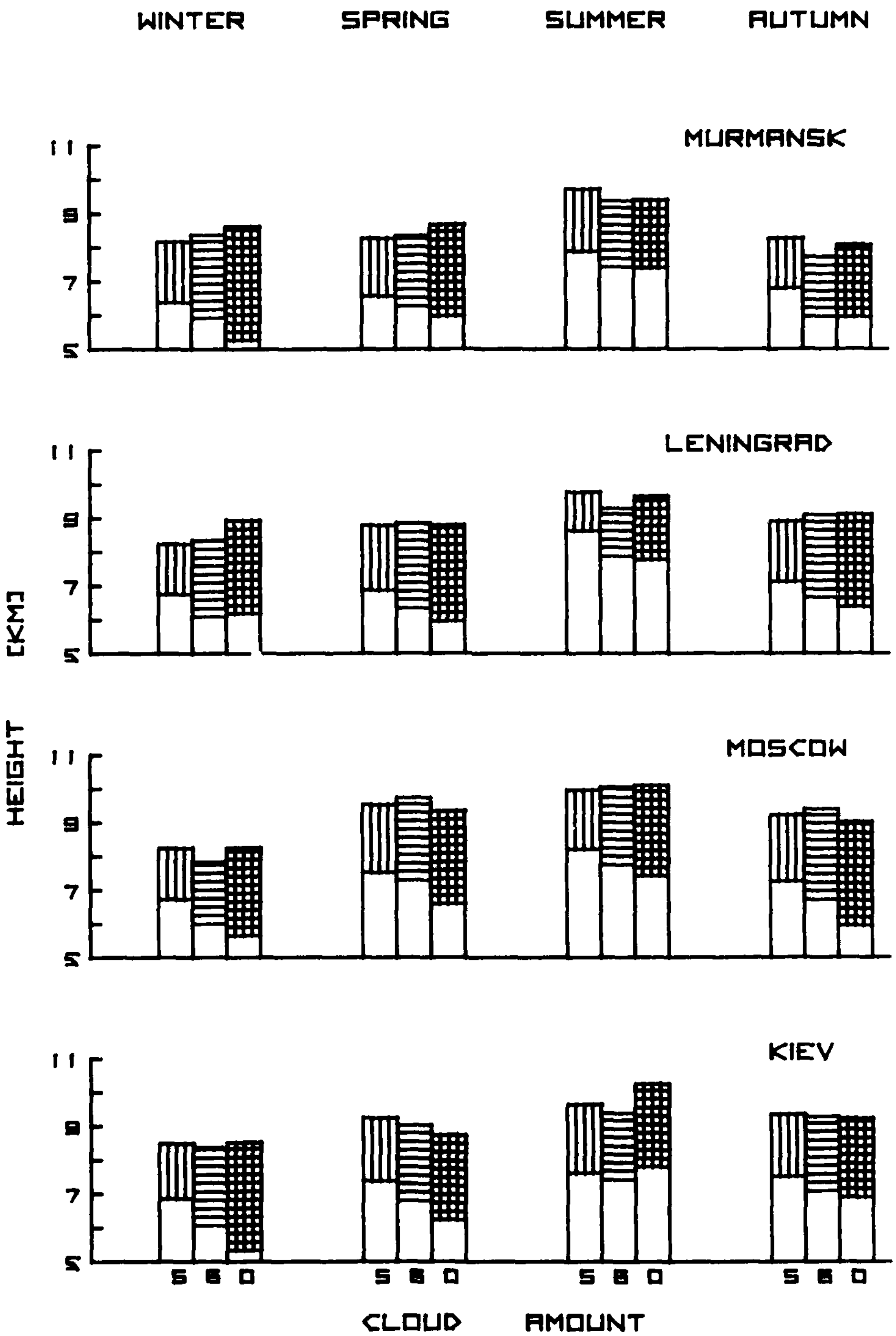

Figure 11a. Seasonal Average Top and Base Heights by Cloud Amount for Murmansk, Leningrad, Moscow, and Kiev

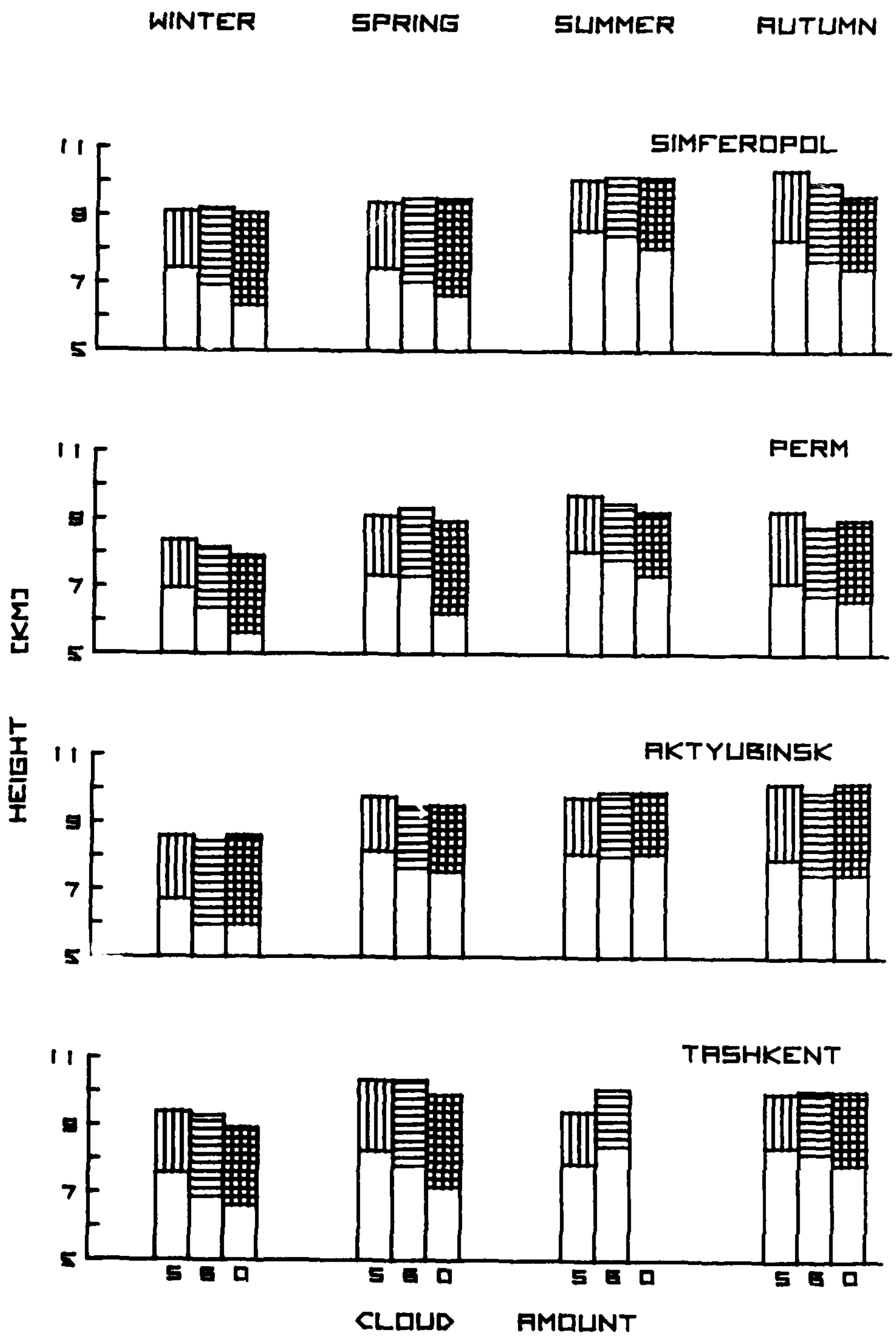

Figure 11b. Seasonal Average Top and Base Heights by Cloud Amount for Simferopol, Perm, Aktyubinsk, and Tashkent

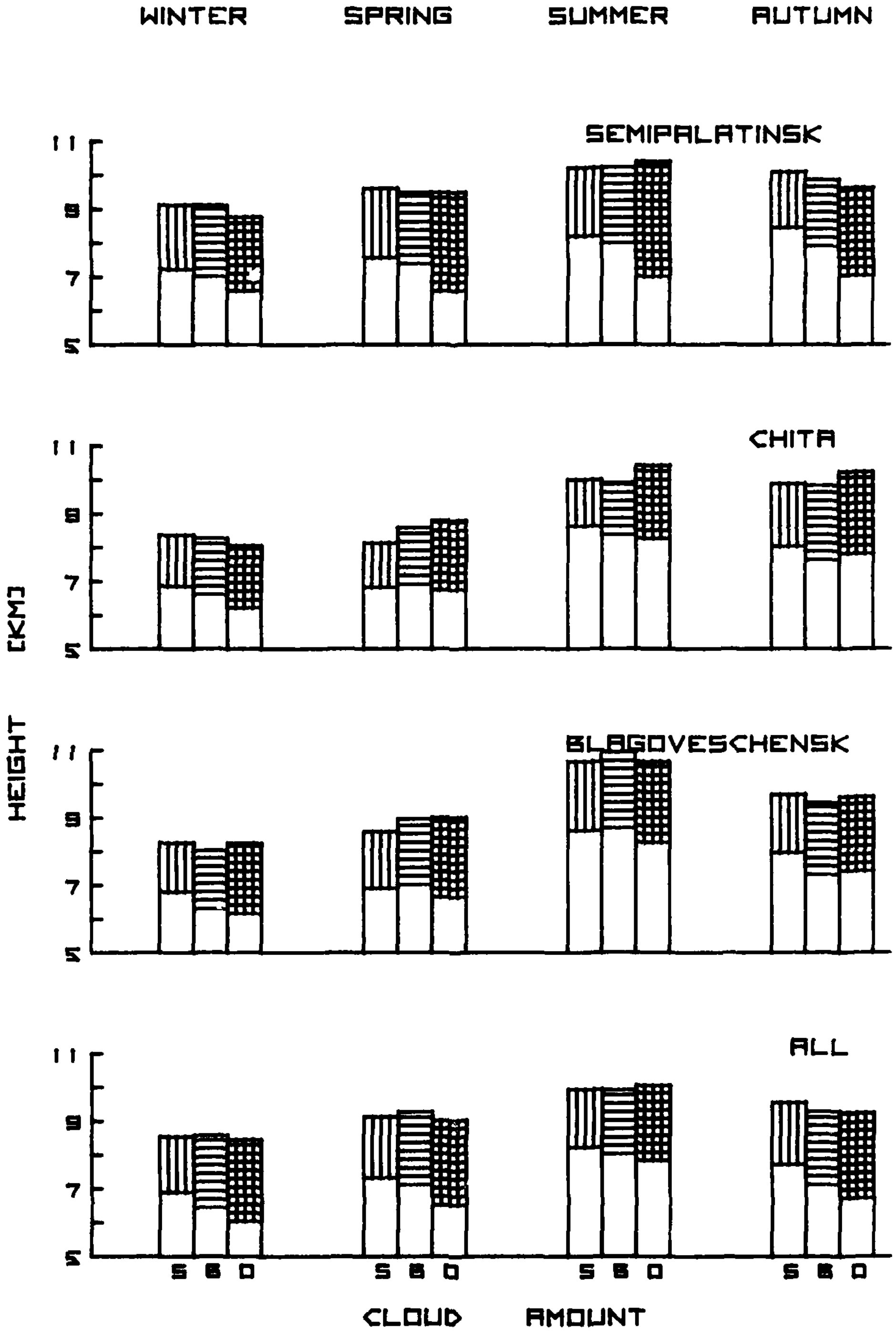

Figure 11c. Seasonal Average Top and Base Heights by Cloud Amount for Semipalatinsk, Chita, Blagoveschensk, and All Stations

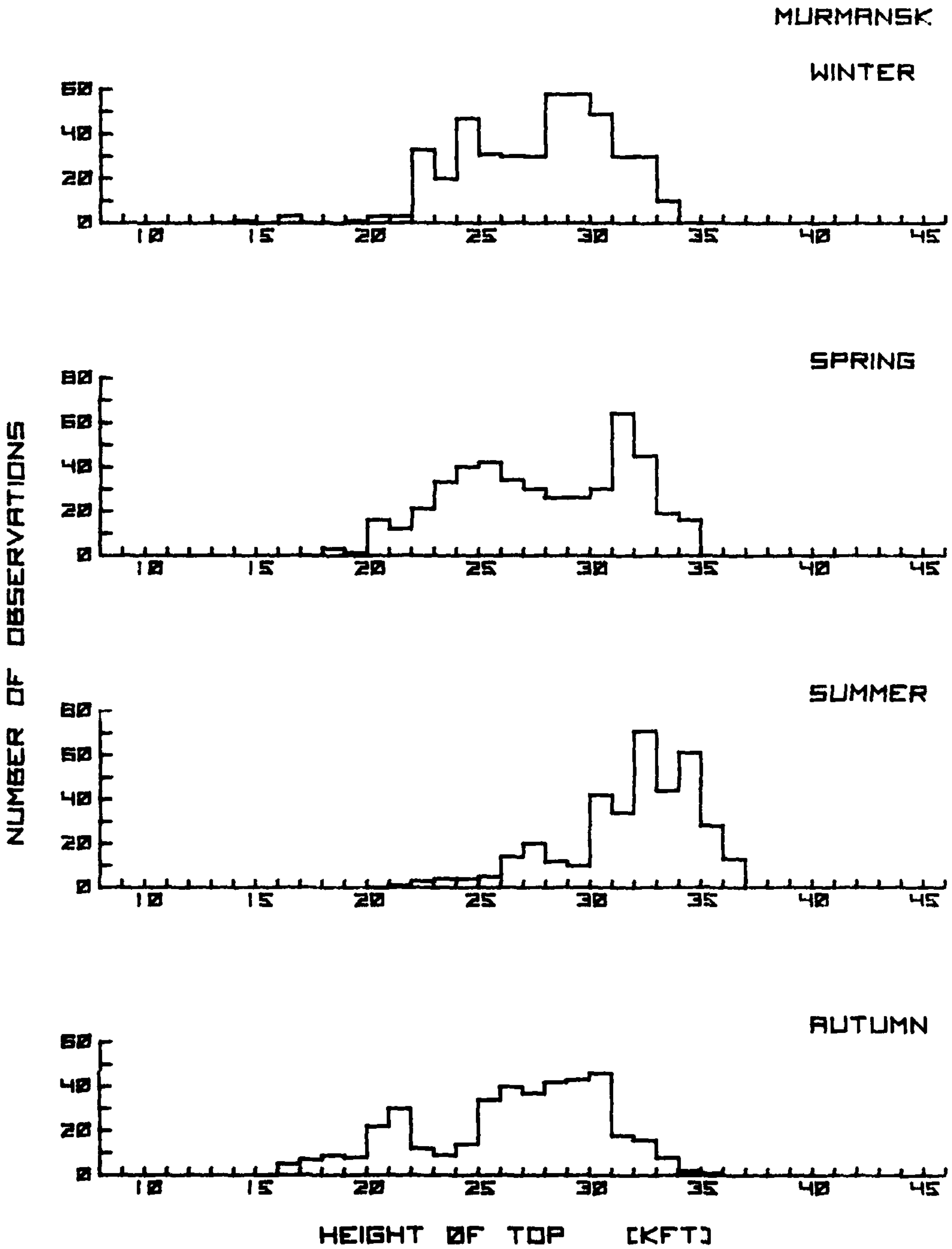

Figure 12a. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Murmansk

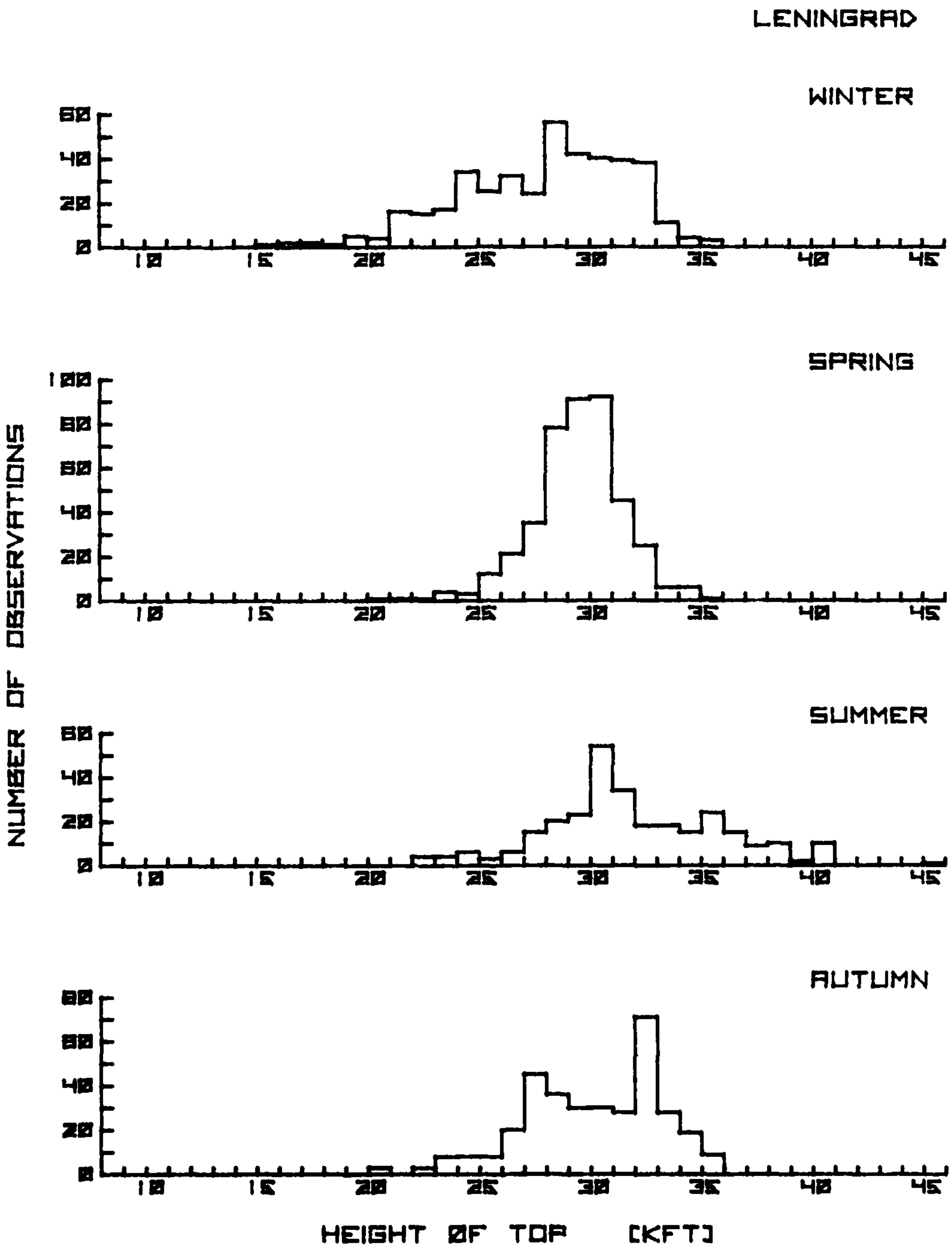

Figure 12b. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Leningrad

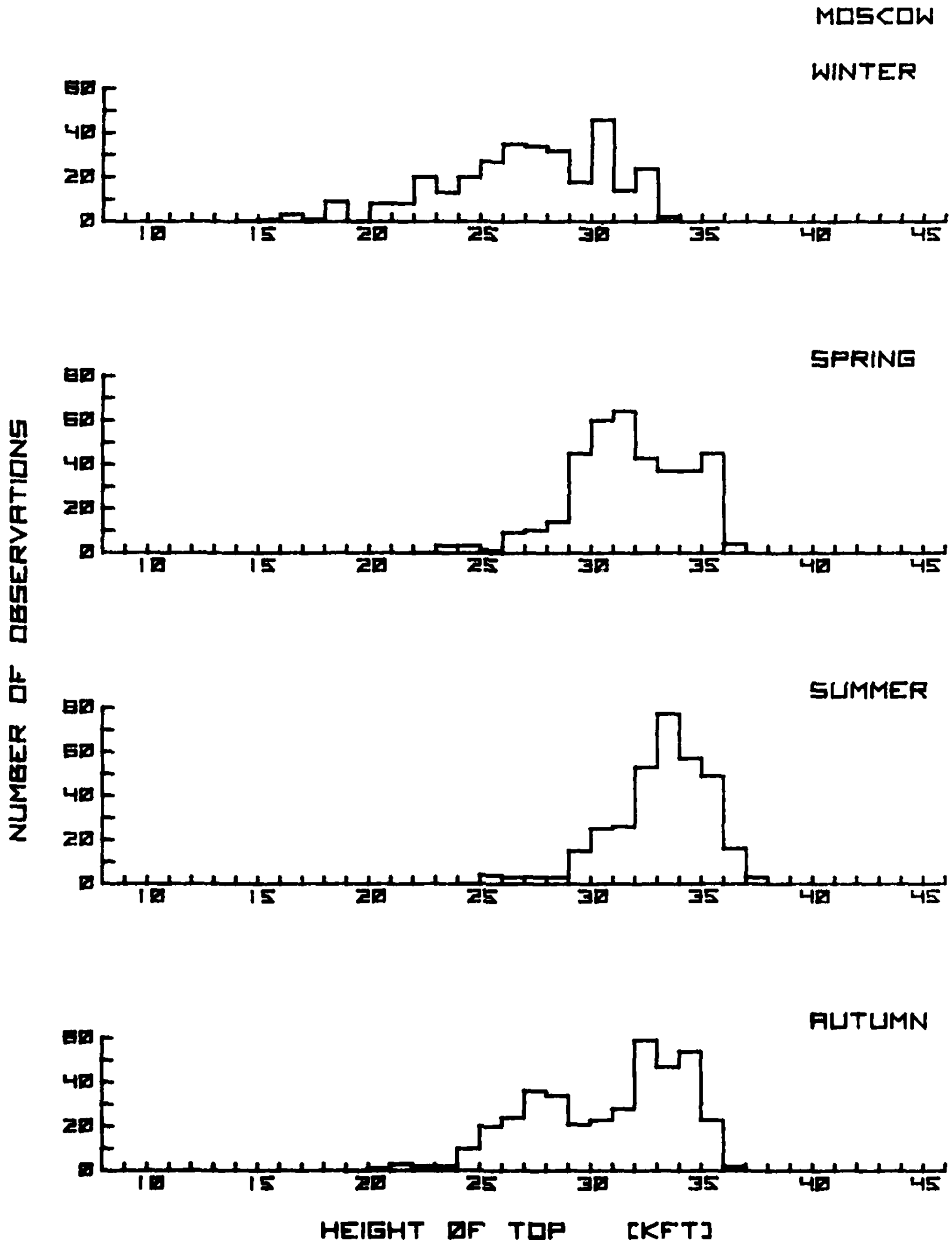

Figure 12c. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Moscow

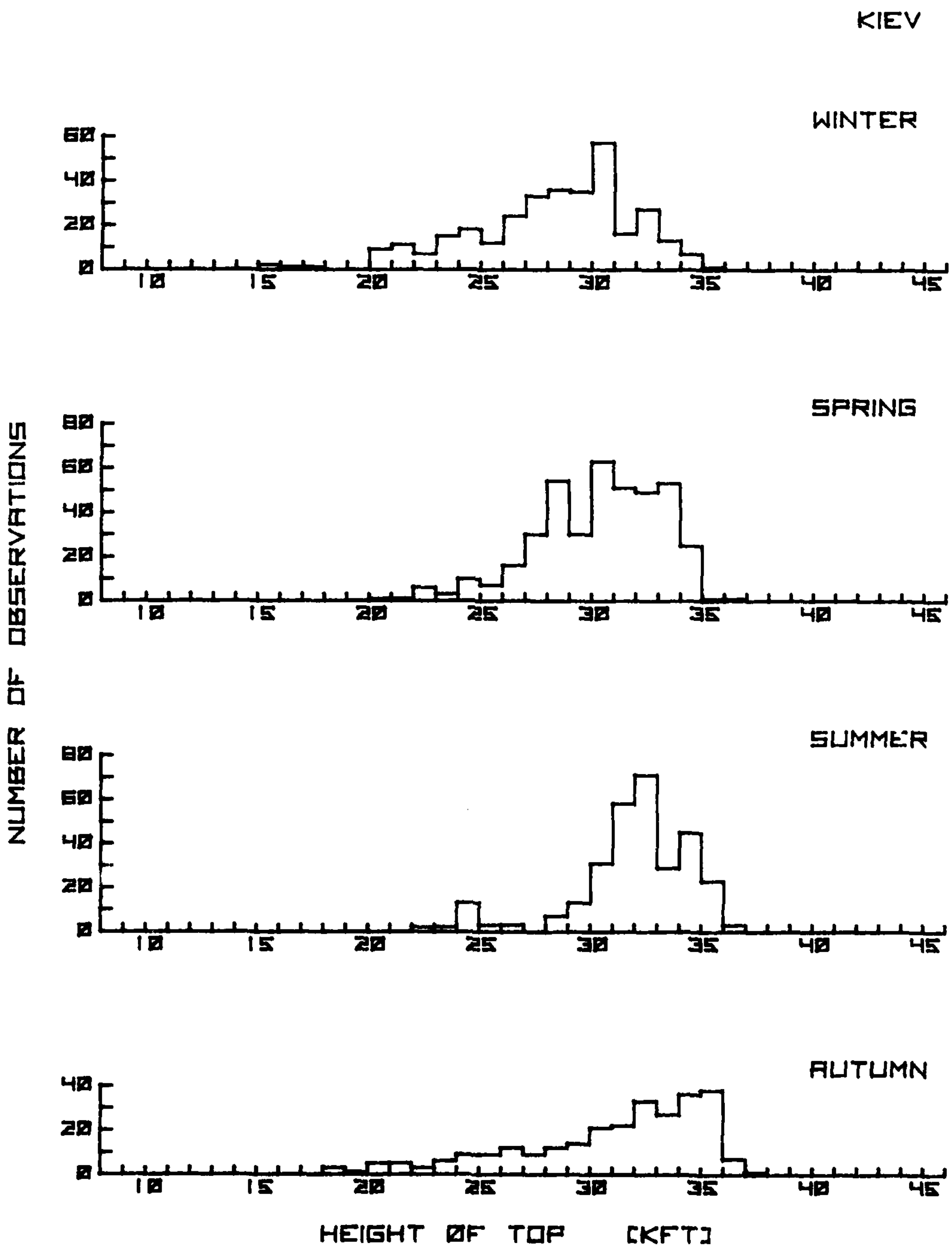

Figure 12d. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Kiev

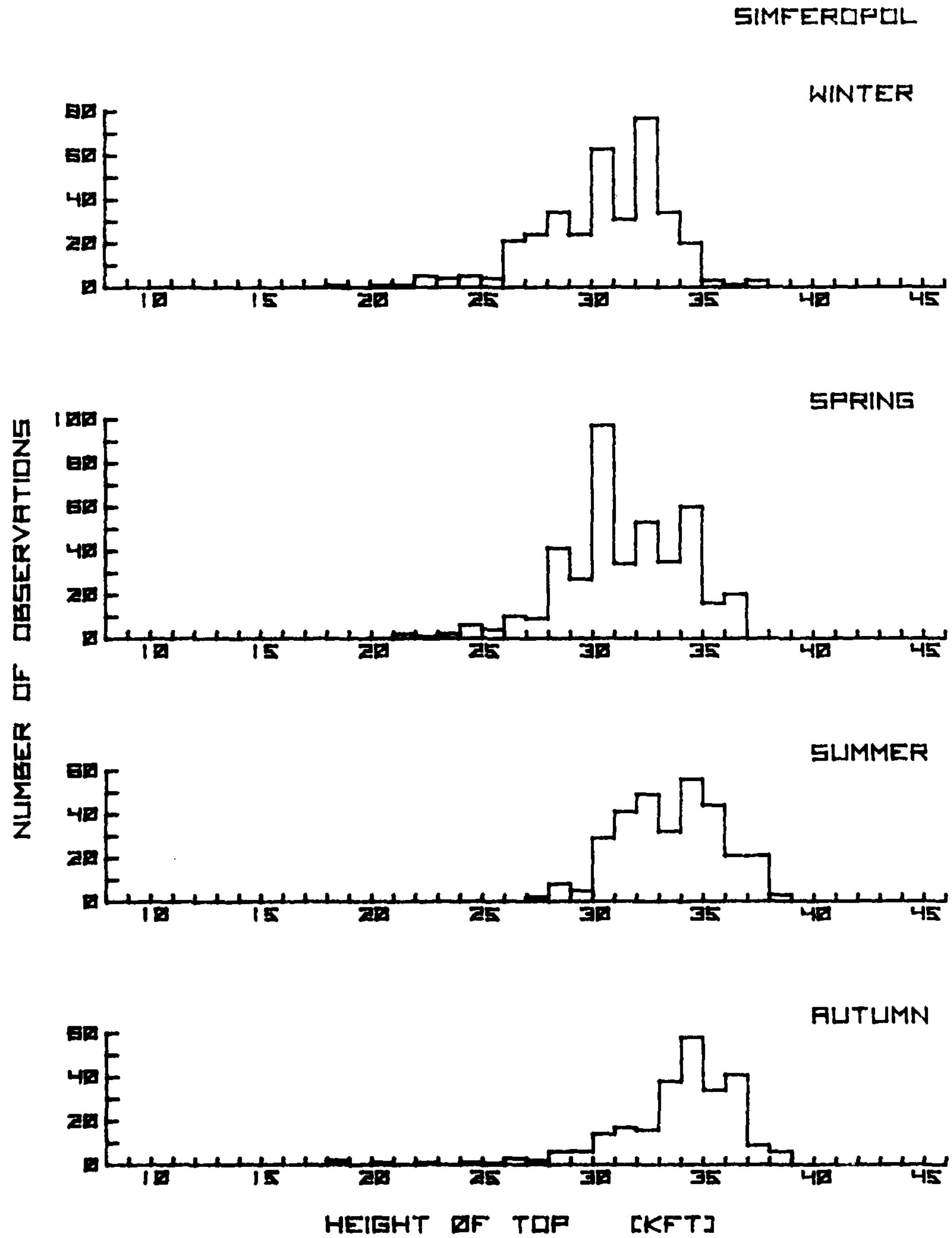

Figure 12e. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Simferopol

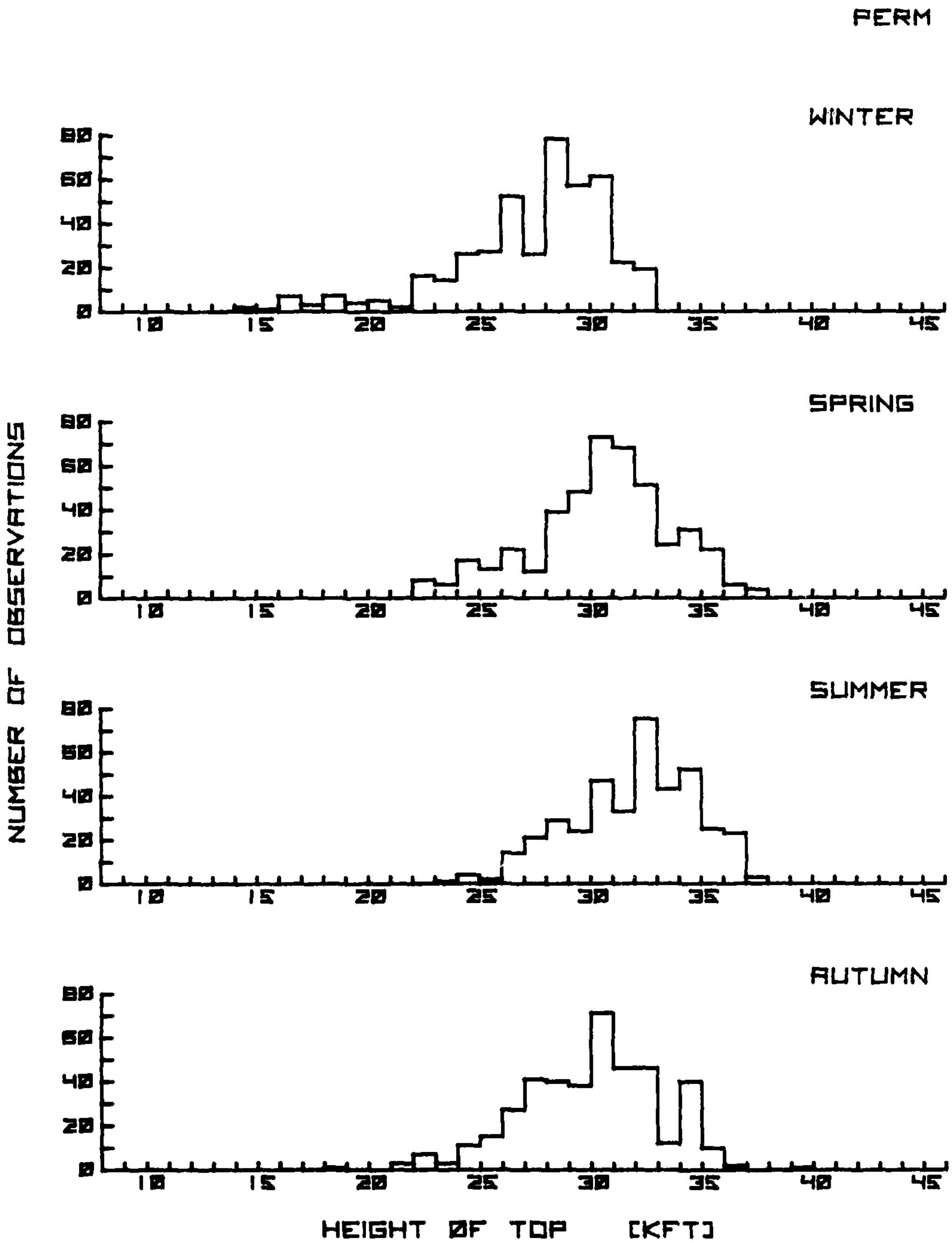

Figure 12f. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Perm

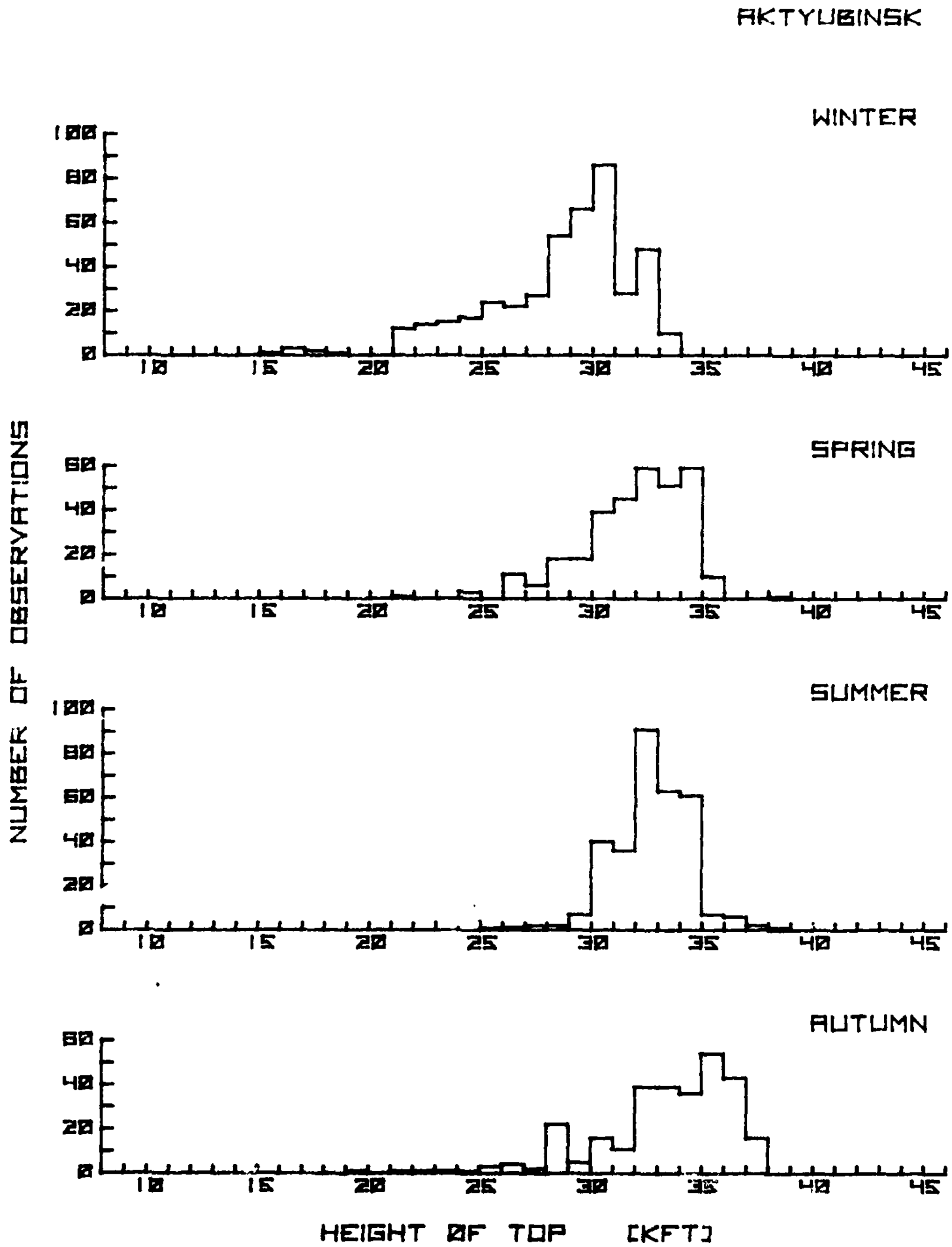

Figure 12g. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Aktyubinsk

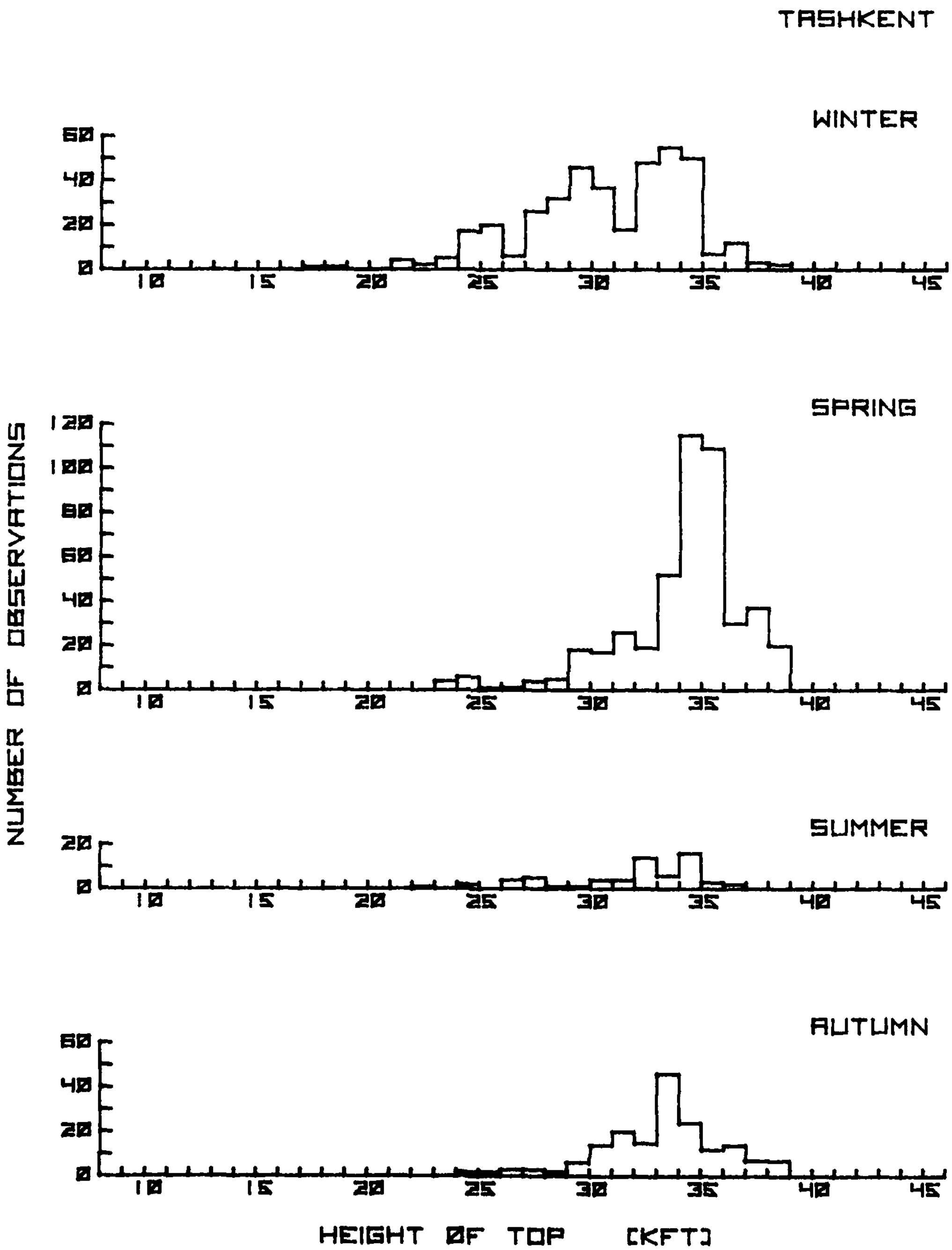

Figure 12h. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Tashkent

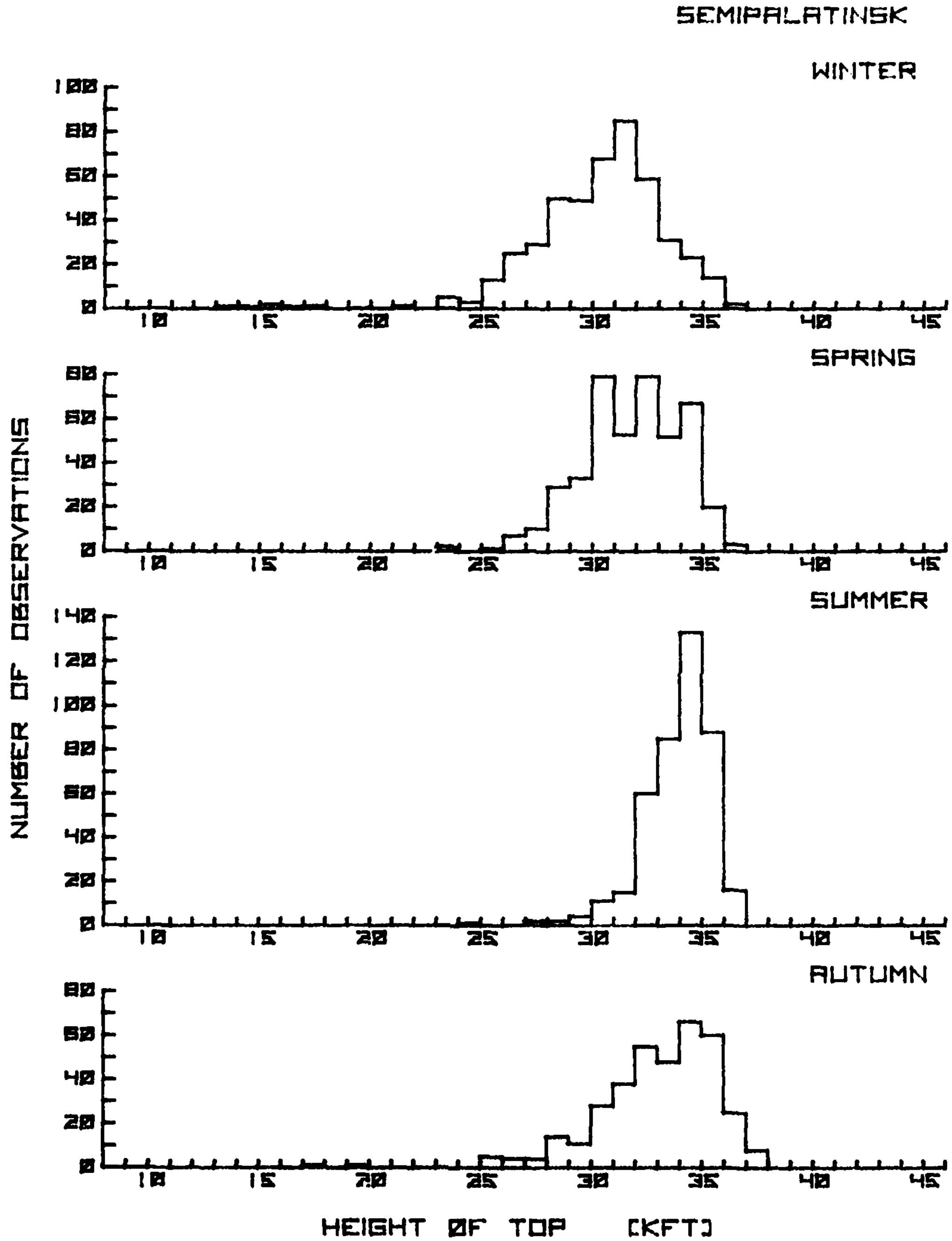

Figure 12i. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Semipalatinsk

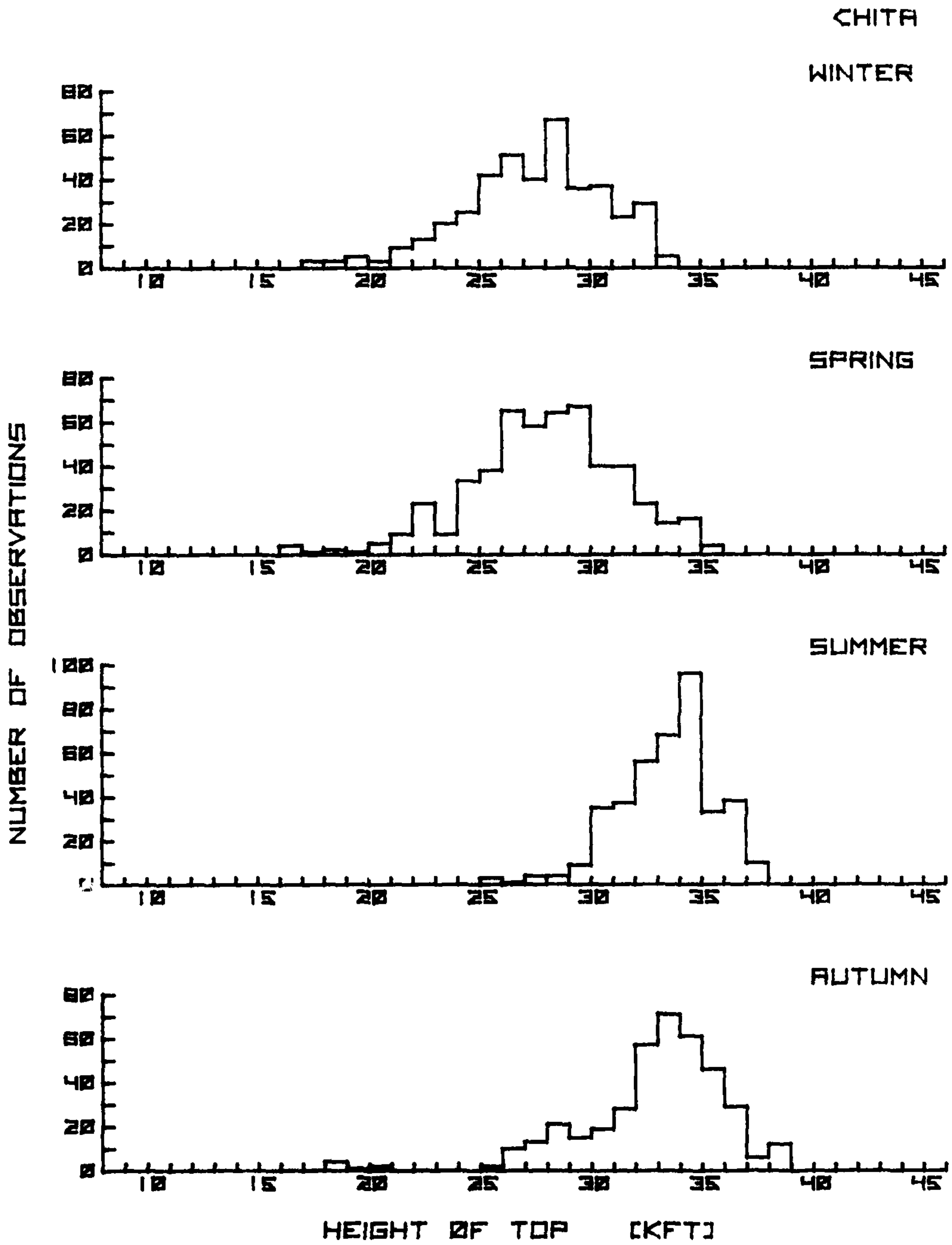

Figure 12j. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Chita

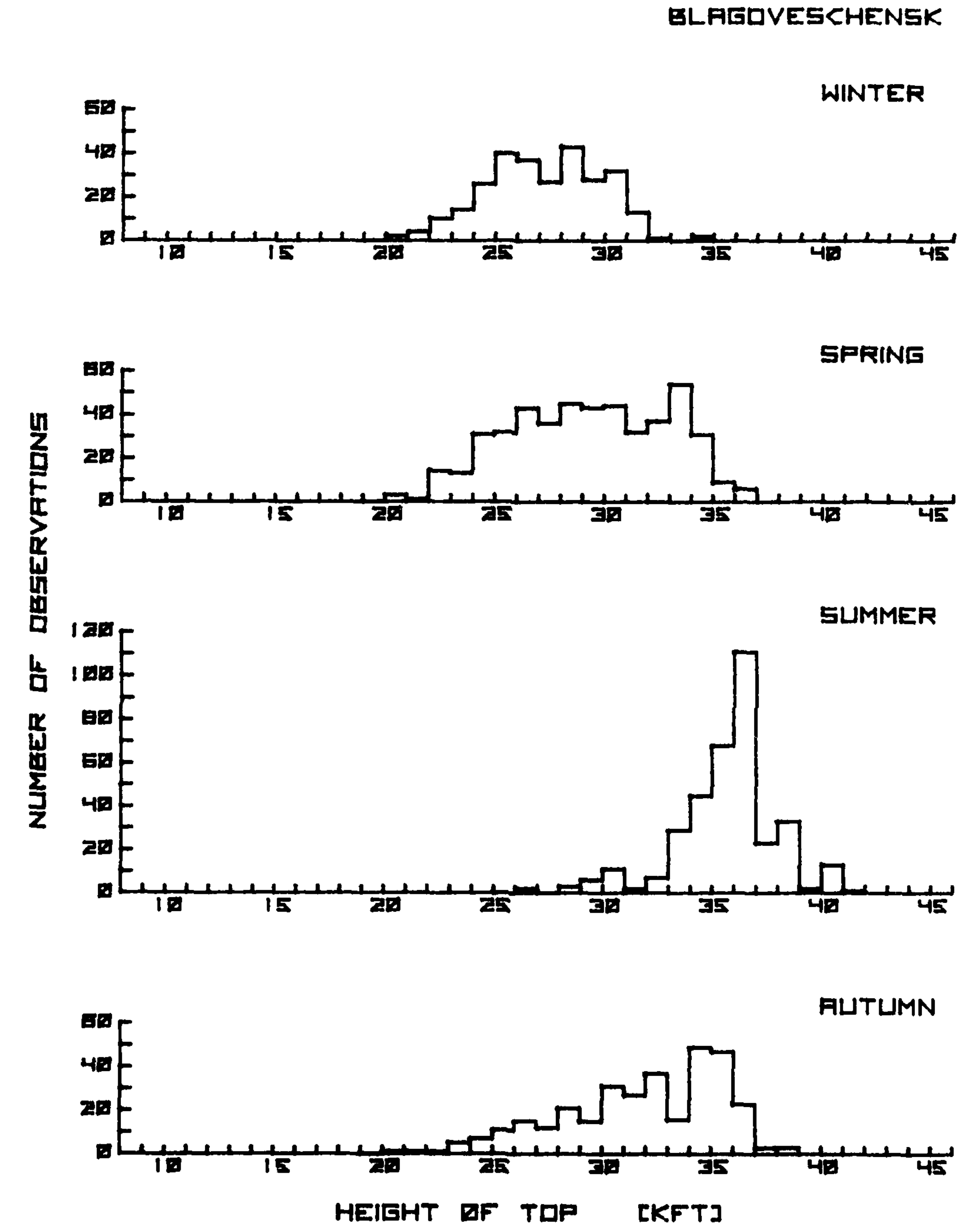

Figure 12k. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops at Blagoveschensk

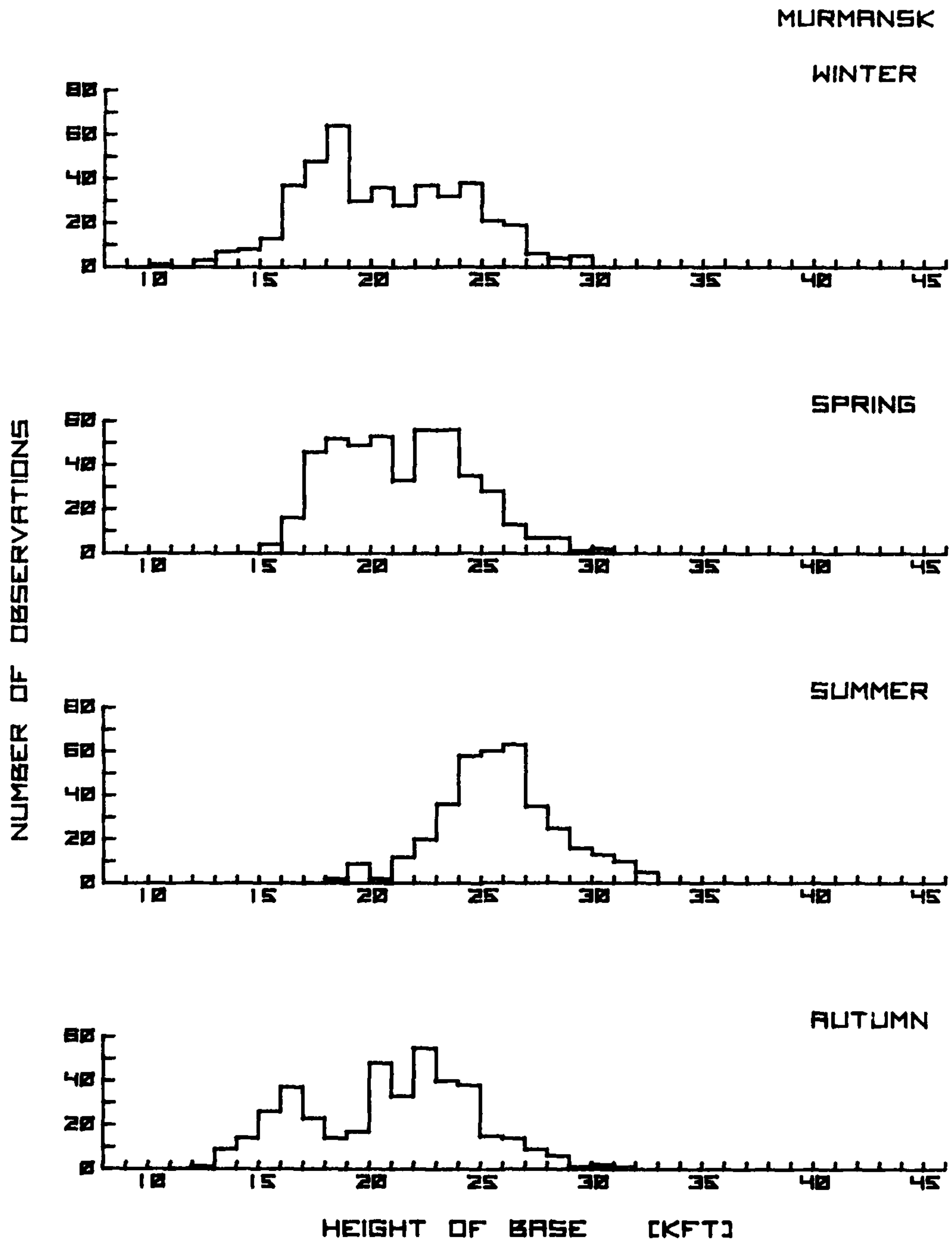

Figure 13a. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Murmansk

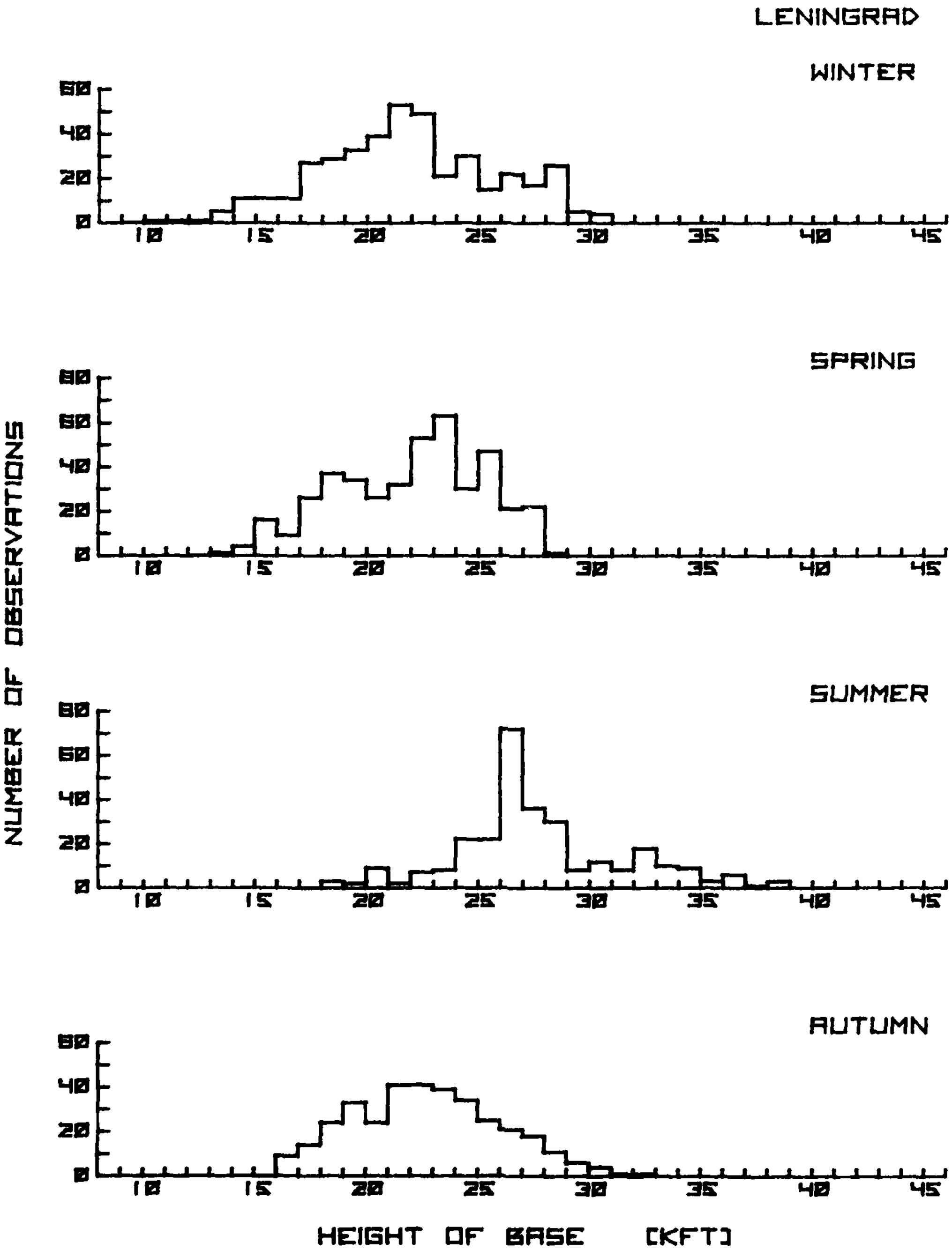

Figure 13b. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Leningrad

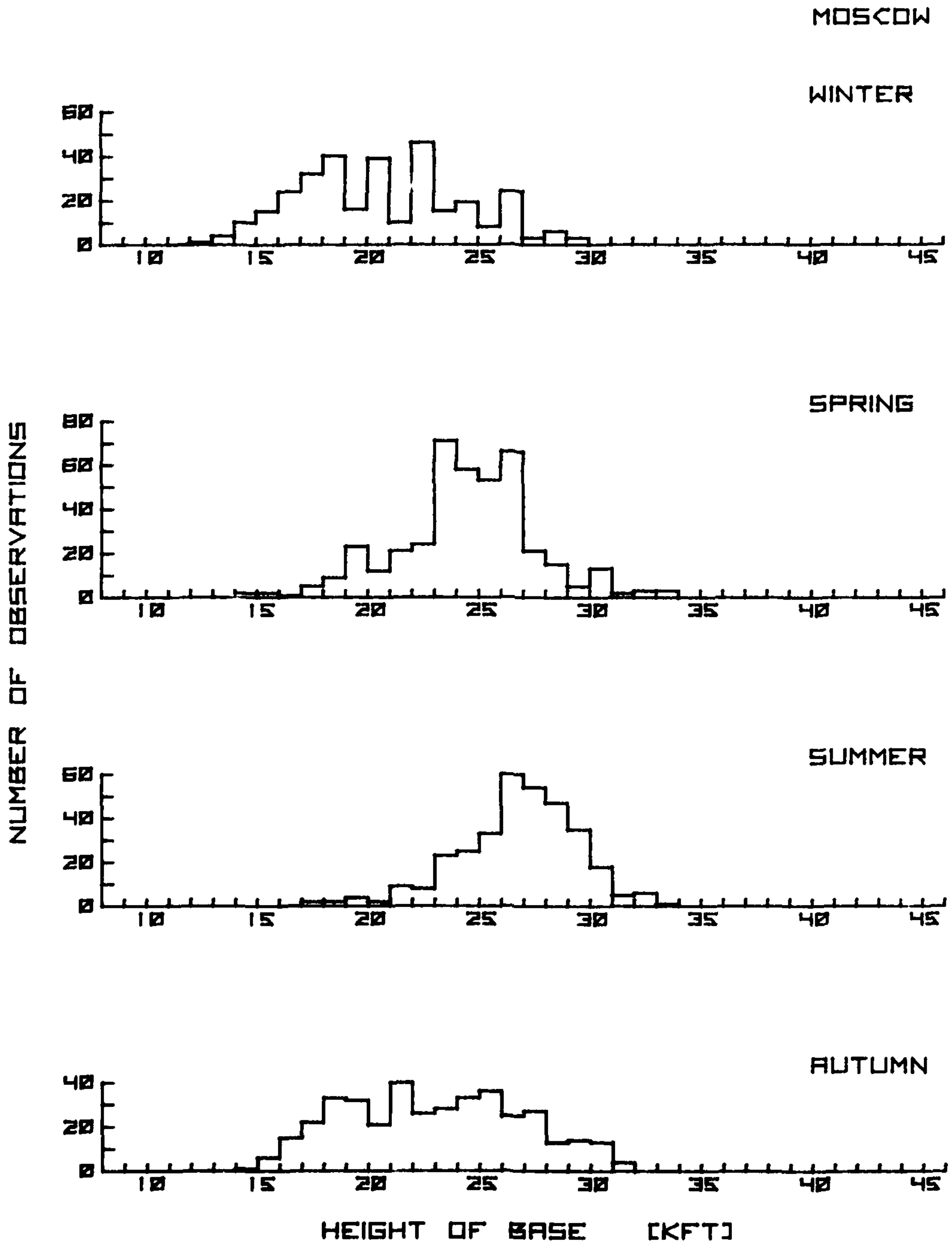

Figure 13c. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Moscow

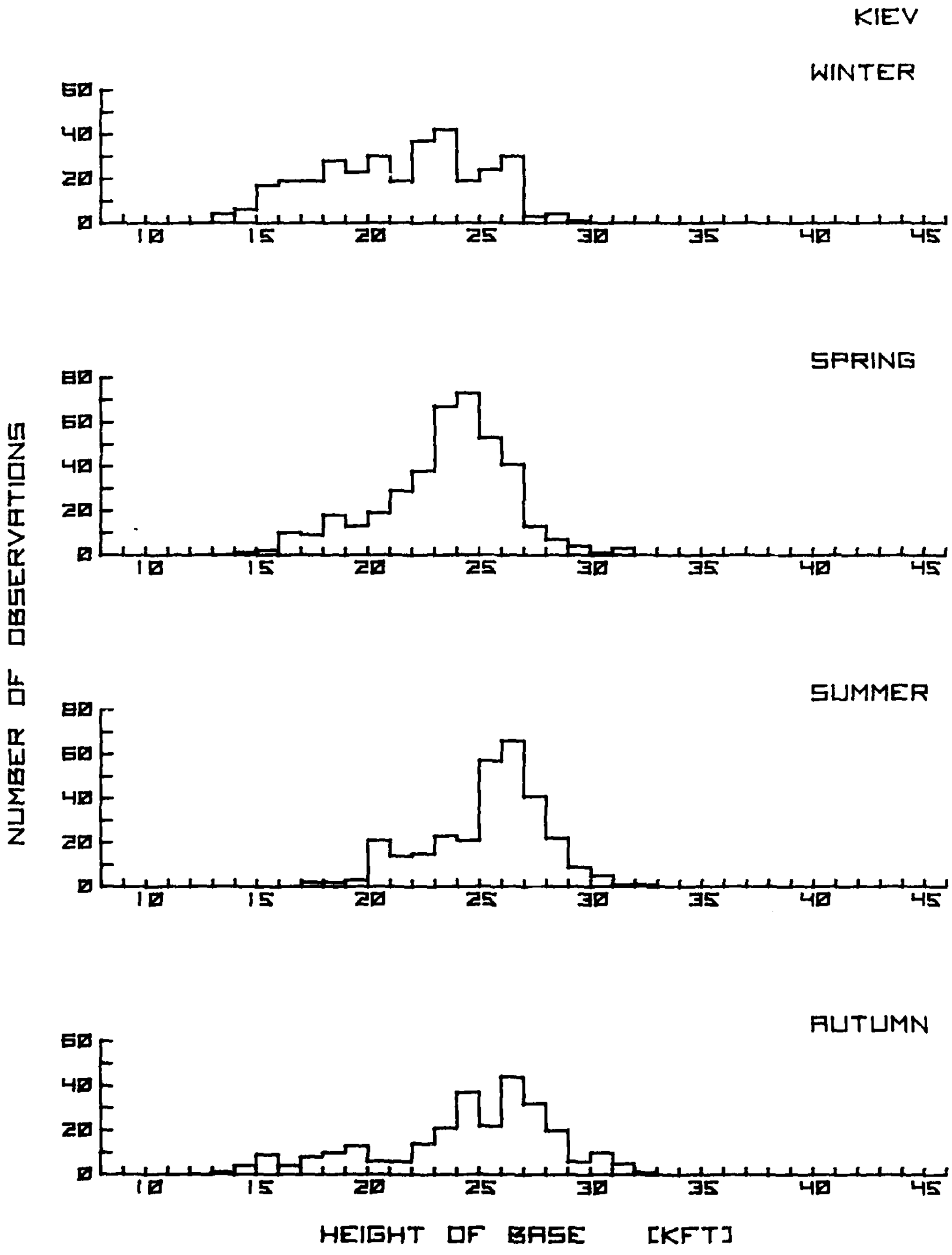

Figure 13d. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Kiev

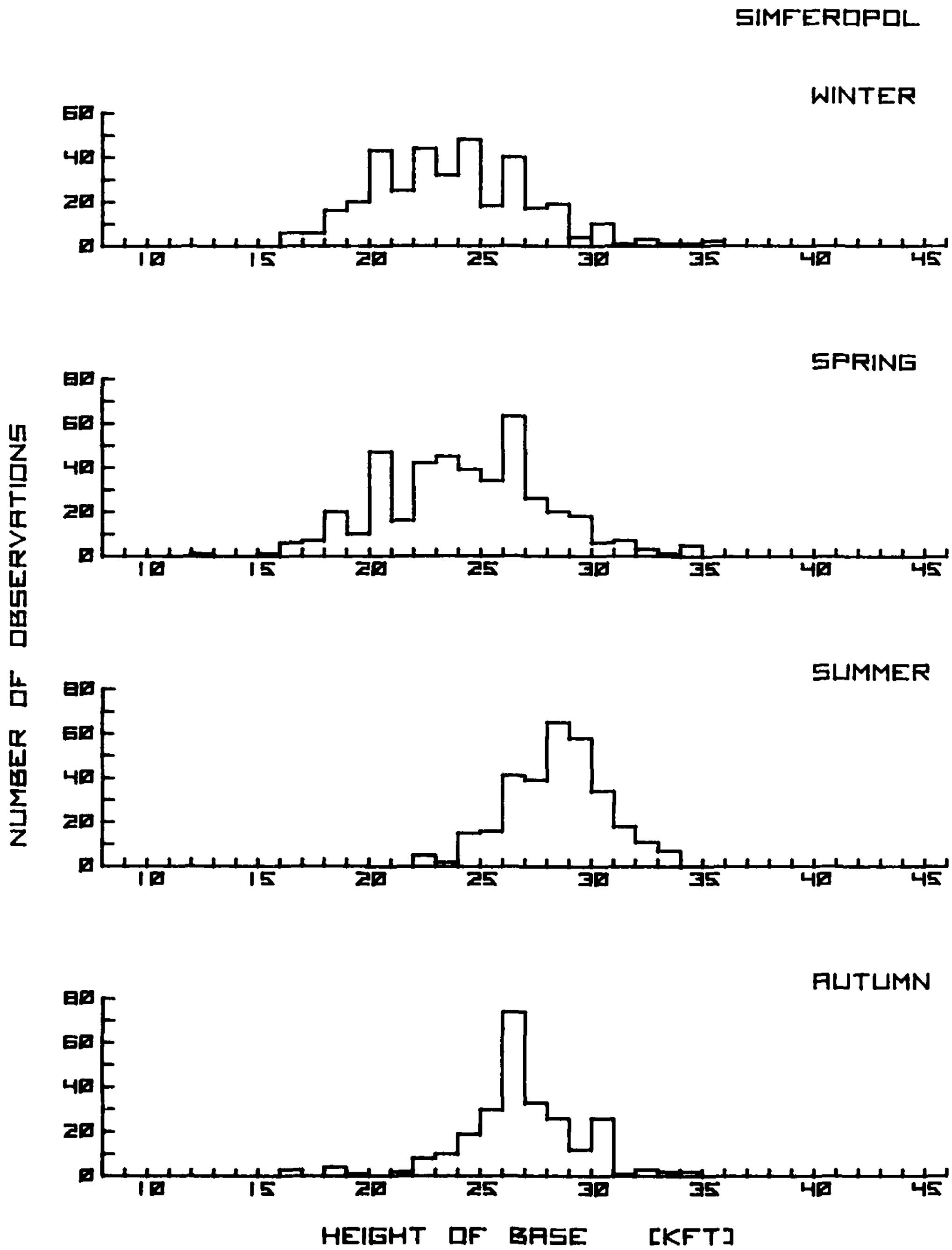

Figure 13e. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Simferopol

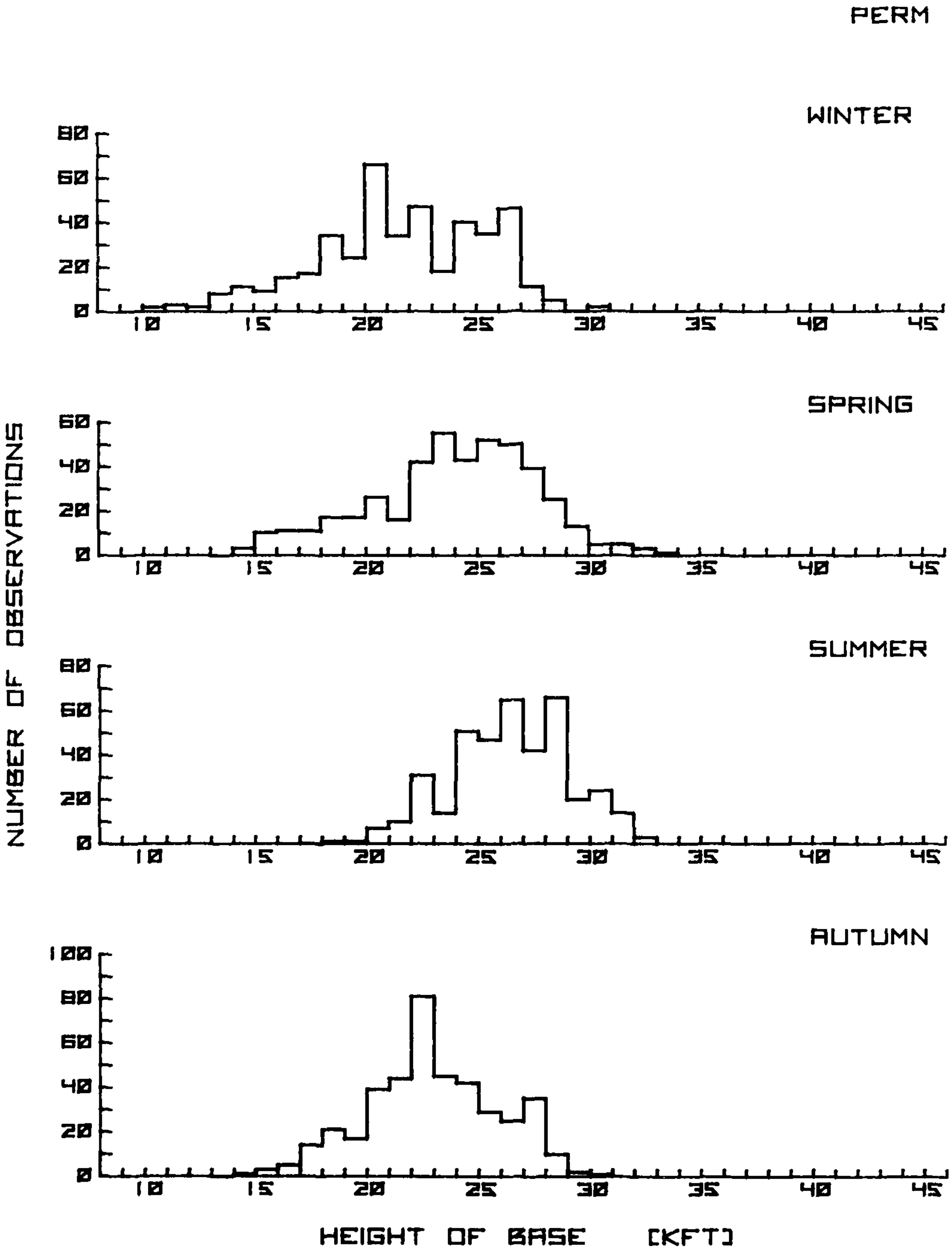

Figure 13f. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Perm

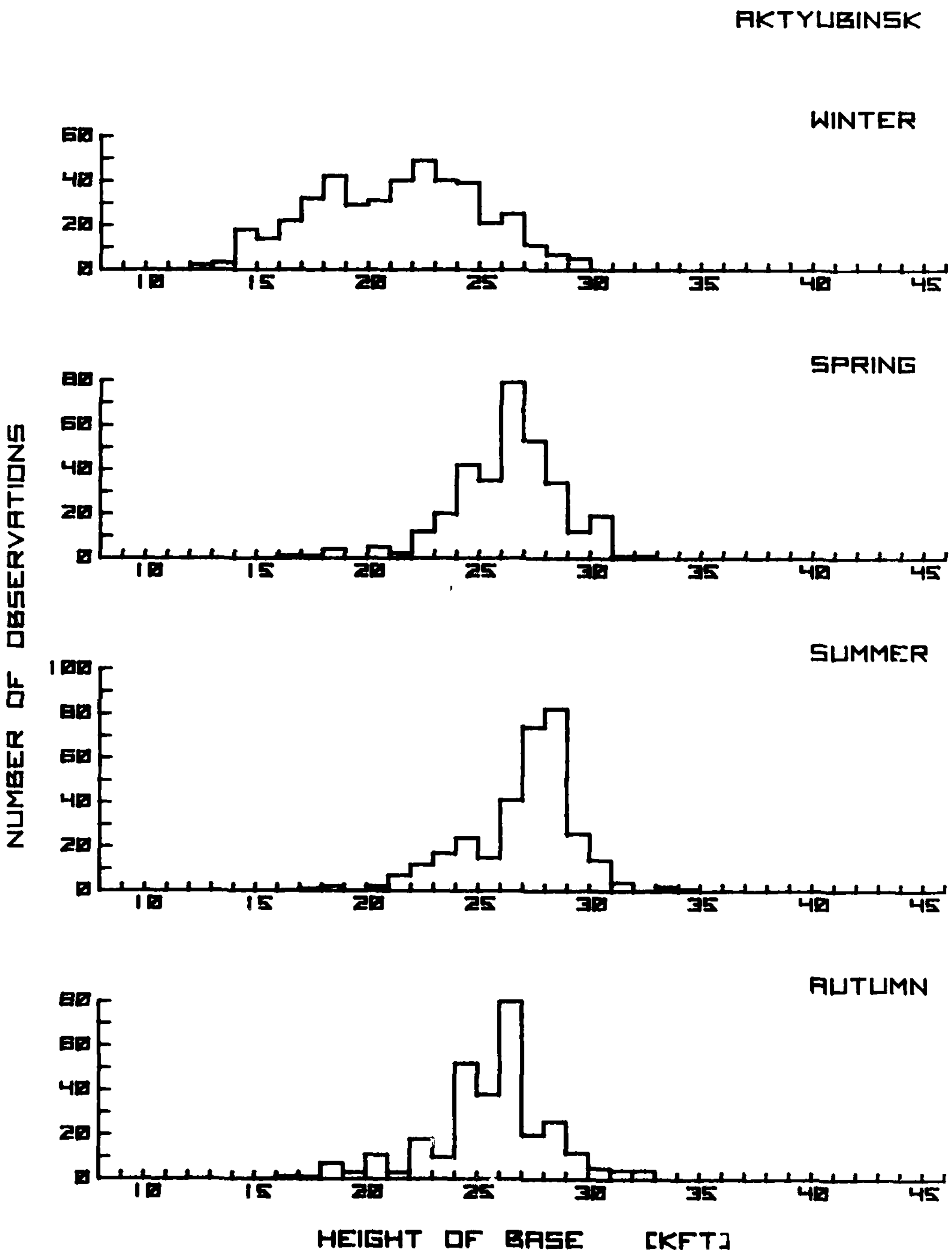

Figure 13g. Seasonal Frequency Distribution of Heights of Cirriform Cloud **Bases at Aktyubinsk**

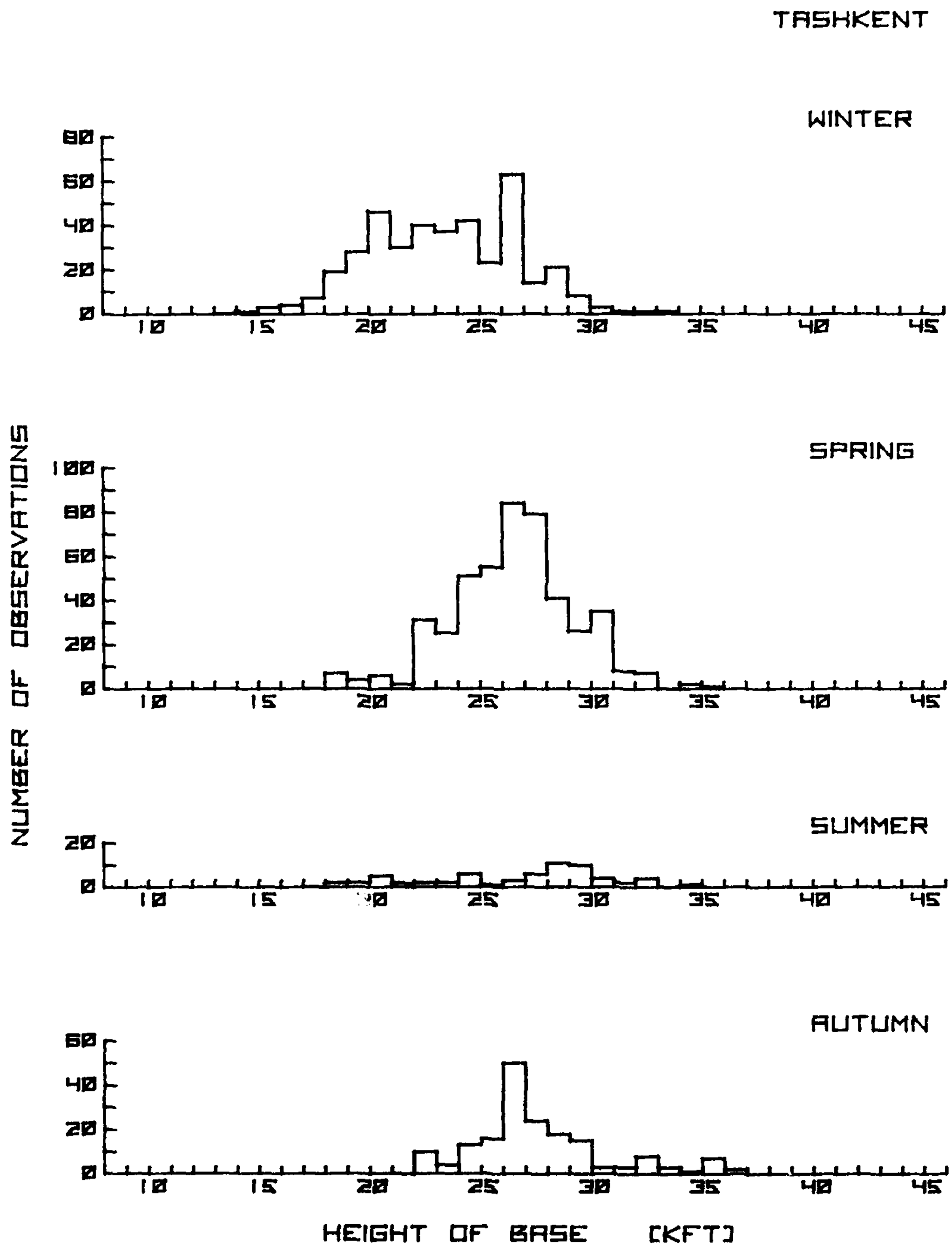

Figure 13h. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Tashkent

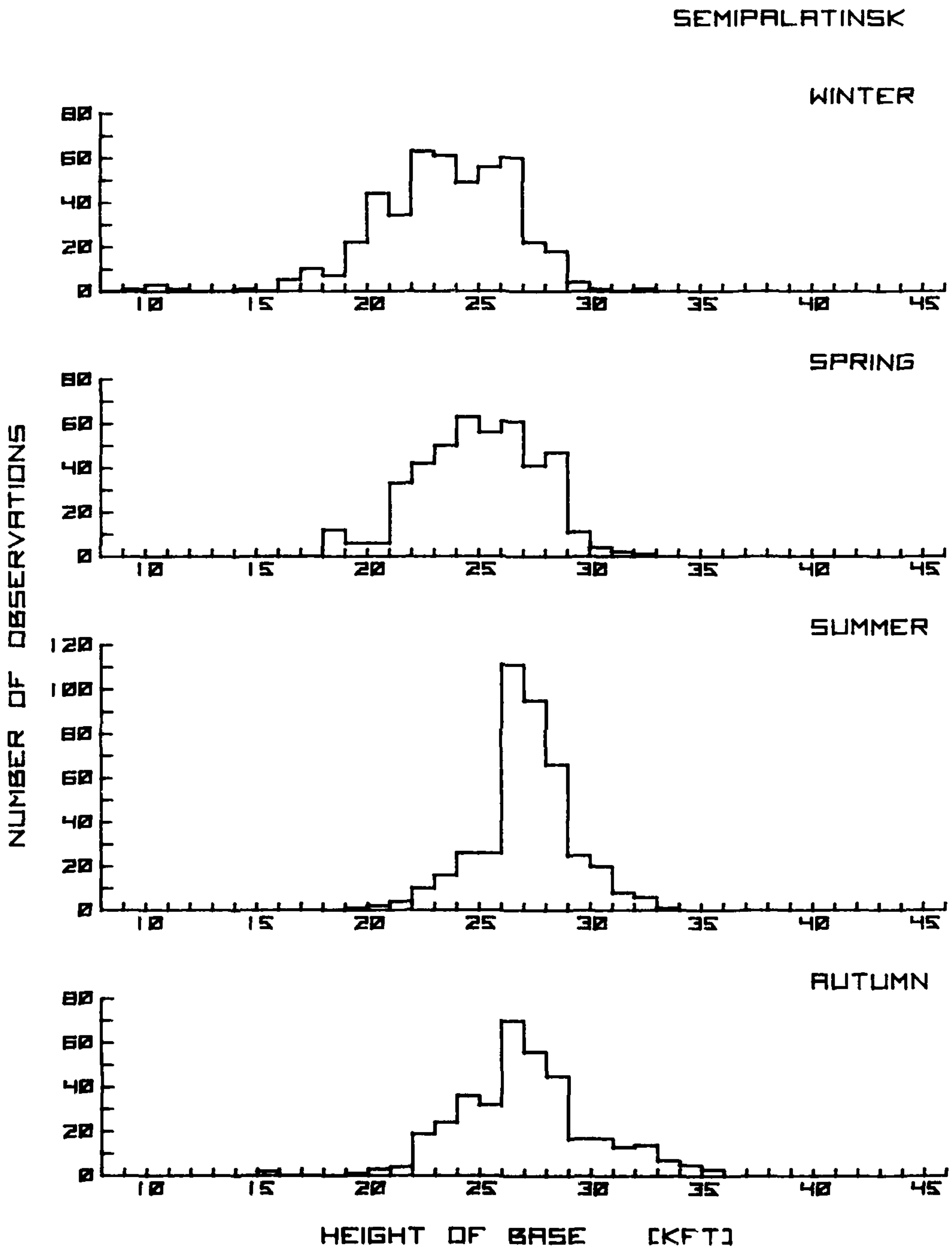

Figure 13i. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Semipalatinsk

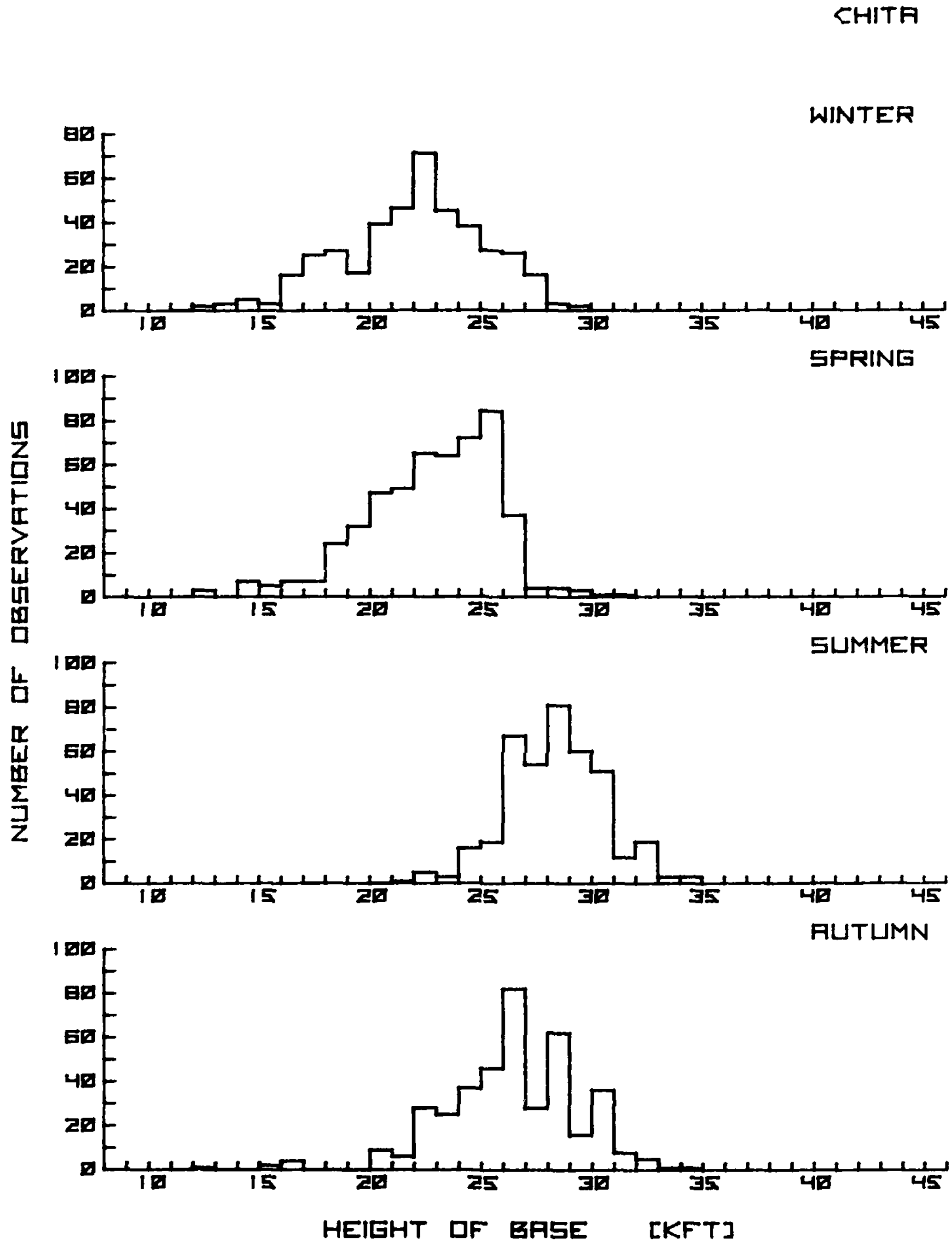

Figure 13j. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Chita

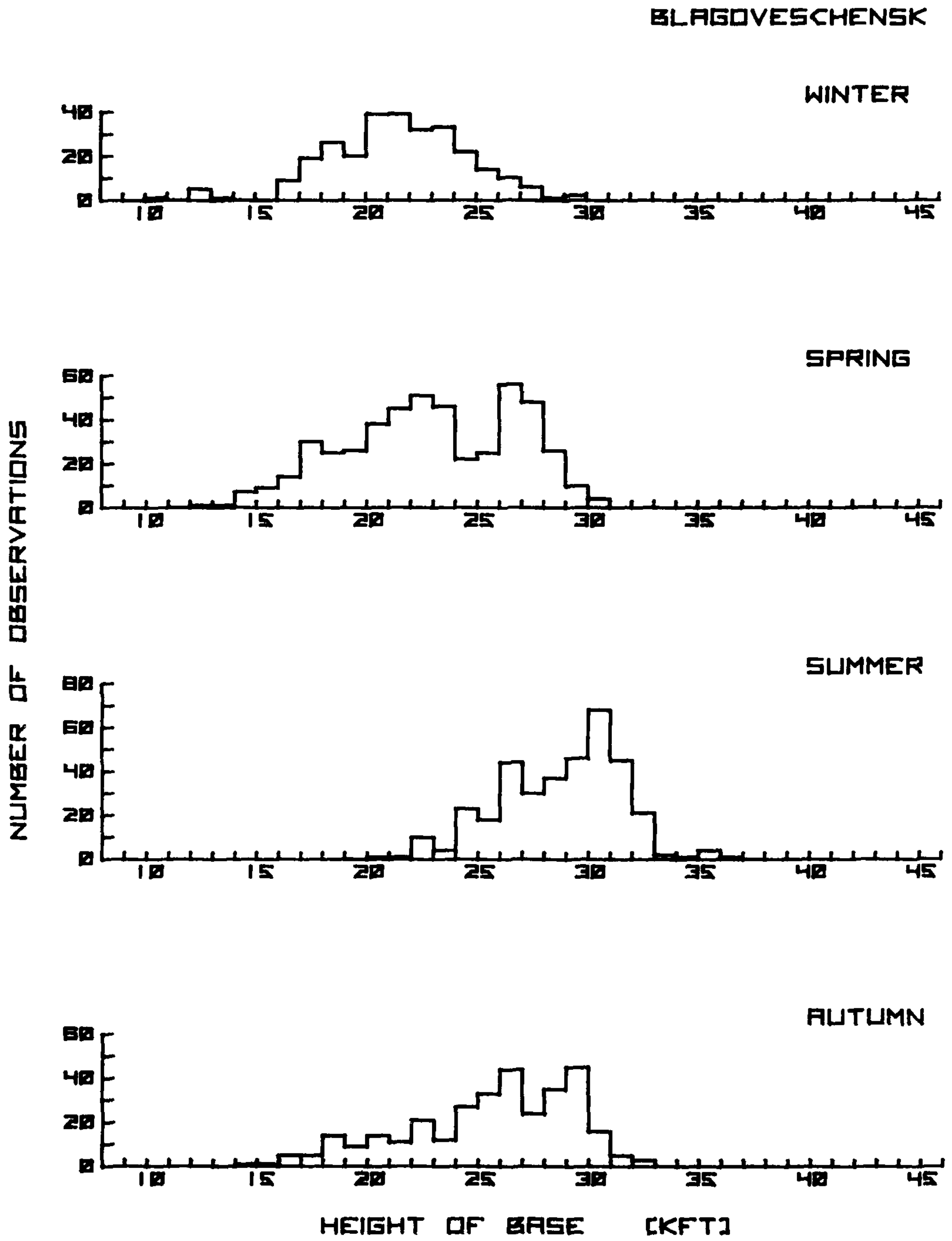

Figure 13k. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases at Blagoveschensk

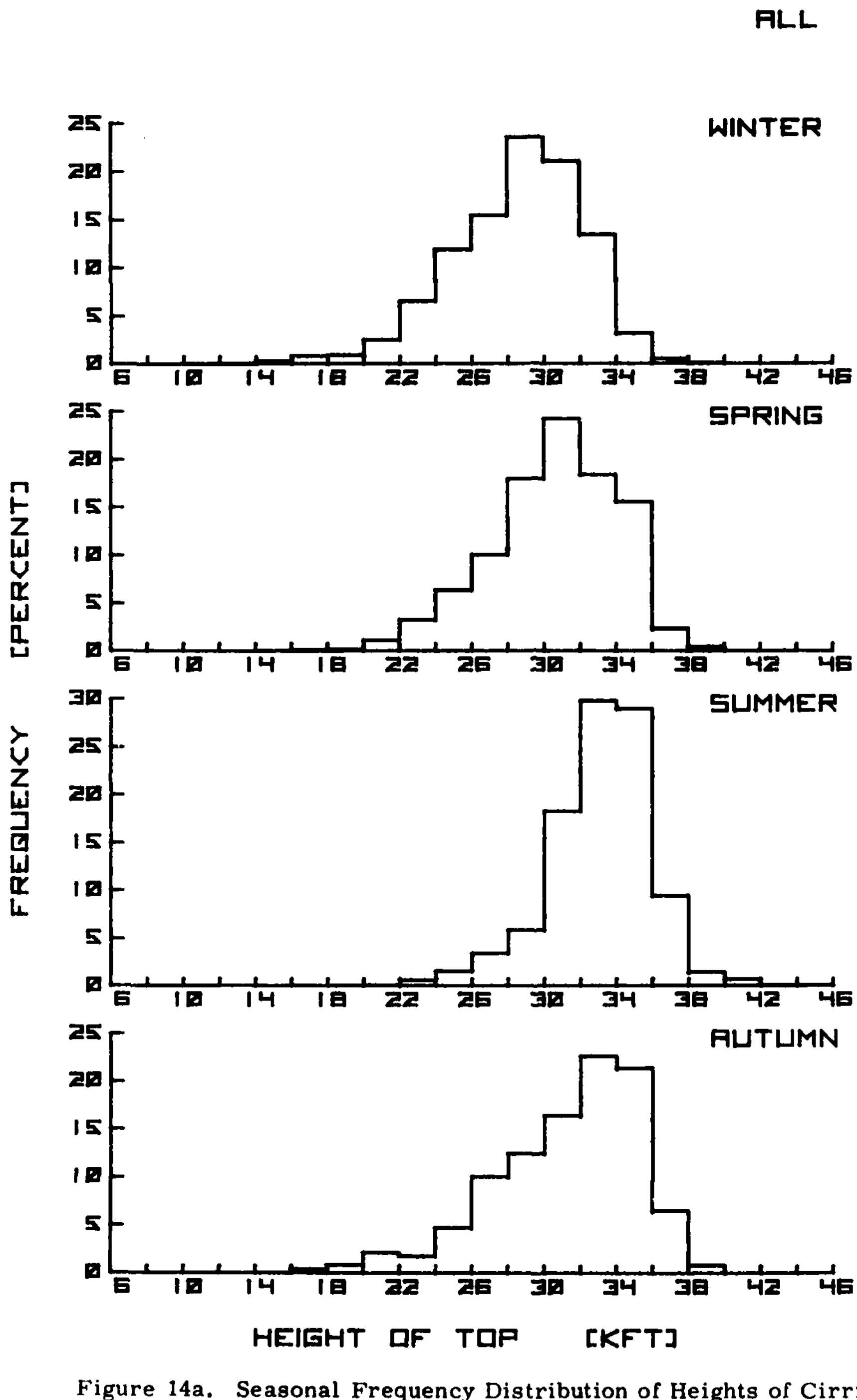

Figure 14a. Seasonal Frequency Distribution of Heights of Cirriform Cloud Tops for All Stations

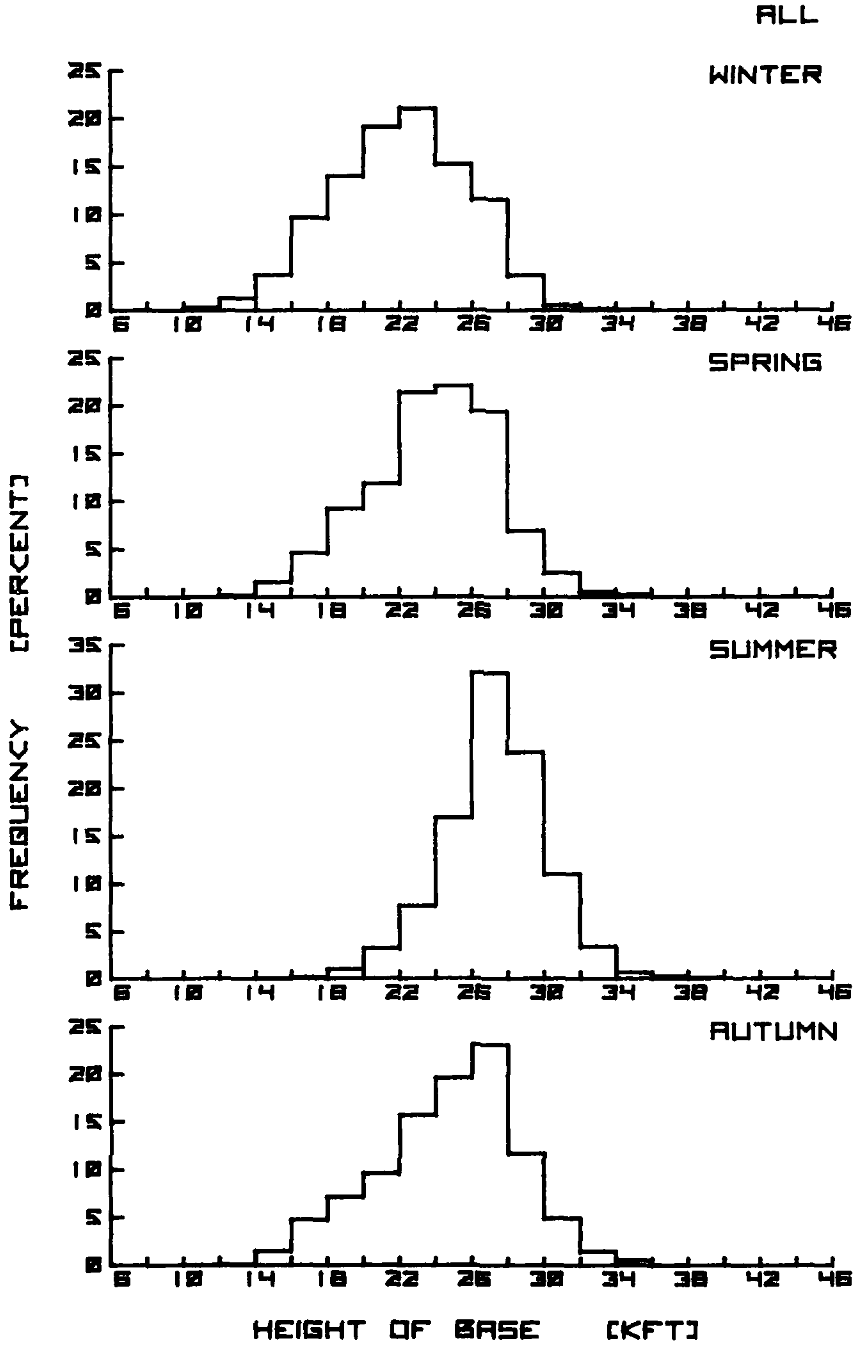

Figure 14b. Seasonal Frequency Distribution of Heights of Cirriform Cloud Bases for All Stations

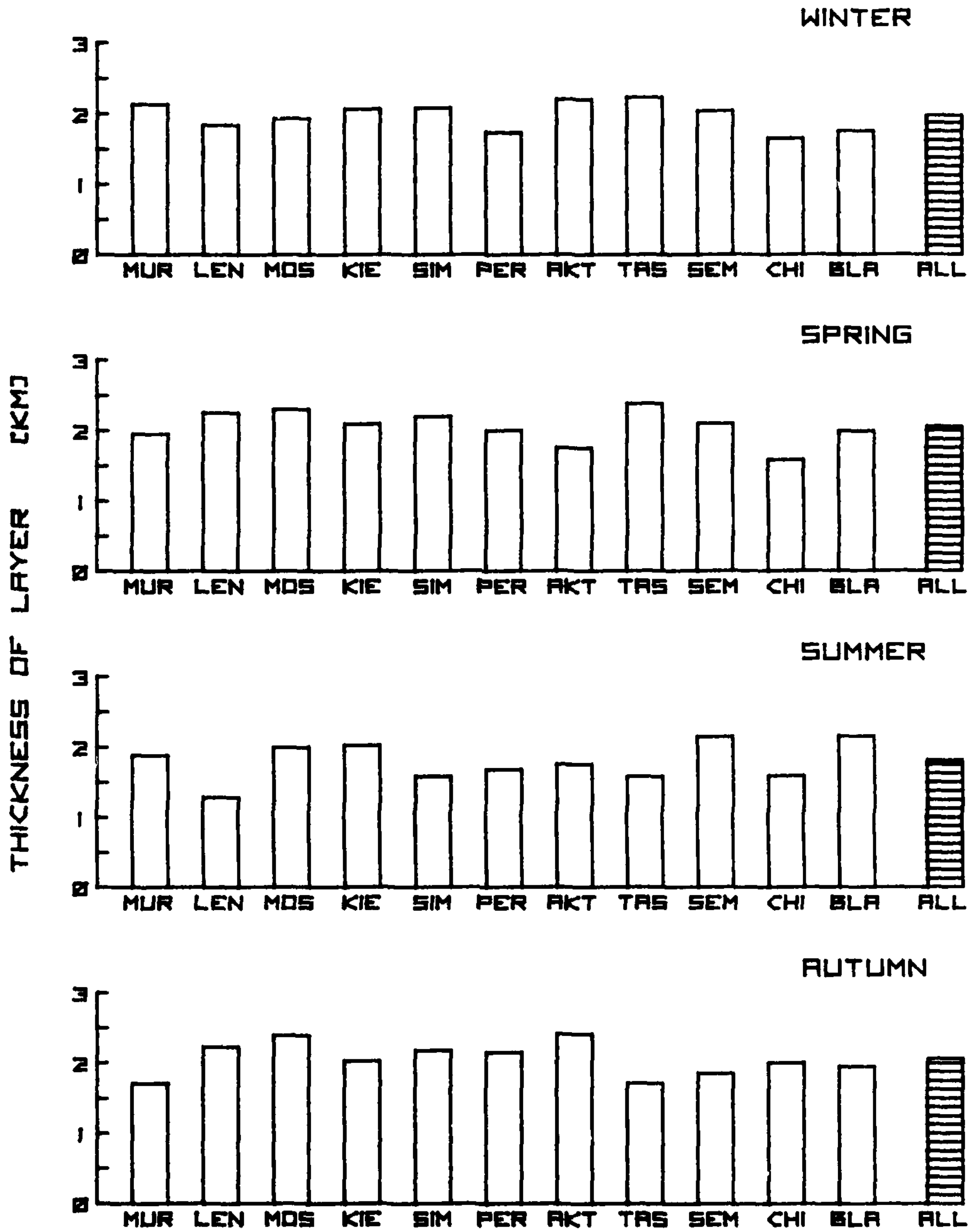

Figure 15. Seasonal Average Thickness of Cirriform Cloud Layers

The average thicknesses of cirrus decks for scattered clouds, broken clouds, and overcast are presented in Figures 16a and 16b. Although the variations are small in the majority of the cases, the cloud layers become thicker with increasing amounts of cloud cover. This is a reflection of the small and erratic variation of the change of top heights and the more systematic and greater decrease of base heights with increasing cloud amount discussed previously.

The frequency distributions of the cloud thickness are shown by seasons for each station in Figures 17a through 17k. Figure 17ℓ shows the distribution for all stations combined. The distributions are shown for intervals of 1000 ft. The complete range of reports in thickness extended from less than 1000 ft to more than 19,000 ft. As with the frequency distribution of top and base heights, the thickness also changes from season to season for each station and no two stations show similar distribution. However, one outstanding feature is that the predominant thickness is found between 4000 and 7000 ft although the range of maximum frequencies is from 2000 to 9000 ft. Considering the figure for all stations combined, the maximum frequency was found at 5000 ft for all four seasons. The most common thickness was between 3000 and 7000 ft with about 56 percent in spring and over 70 percent in winter accounting for all the cases in this range.

3.4 Liquid Water Content of Cirrus

The seasonal average LWC values of the 11 stations together with the value averaged over all stations are shown in Figure 18. The values ranged from a low of 0.010 g/m^3 at Tashkent in summer to a very high value of 0.138 g/m^3 at Perm in summer. The all-station values varied from 0.019 g/m^3 in winter through 0.022 g/m^3 in spring and autumn, to 0.033 g/m^3 in summer.

Figures 19a through 19k show by season the frequency distribution of LWC at intervals of 0.01 g/m^3 for each station and in Figure 19ℓ for all stations combined. The first interval is for values below 0.01 g/m^3 and the last for those greater than or equal to 0.10 g/m^3. It can be seen that in the majority of the cases the maximum frequencies are found between 0.01 and 0.02 g/m^3. Interestingly, the stations and seasons showing maximum or near maximum frequencies at LWC values of less than 0.01 $gm/^3$ are Murmansk, Leningrad, Kiev, and Aktyubinsk during the winter and summer seasons only (Tashkent in summer is not included in this discussion because of the small sample size). Figure 17 shows that the three most western stations and Aktyubinsk do not necessarily record low values of LWC as expected. However, Figures 6a through 6f, displaying the monthly average LWC values, show that these four stations had, without exception, the lowest LWC in the month of February and the next to the lowest LWC in the month of July. Coincidentally or not, none of the other stations show similar features.

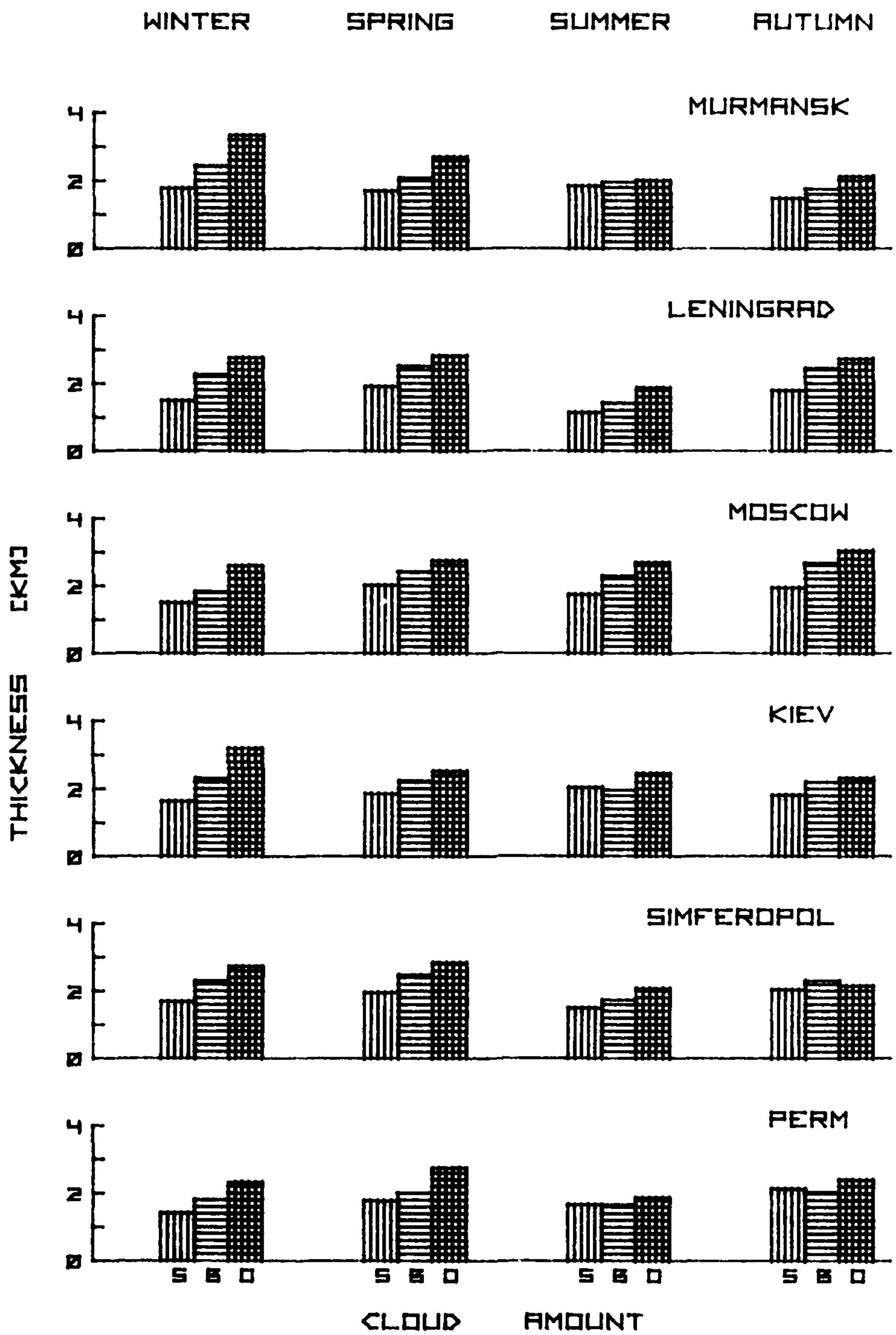

Figure 16a. Seasonal Average Thickness of Cirriform Cloud Layer by Cloud Amount for Murmansk, Leningrad, Moscow, Kiev, Simferopol, and Perm

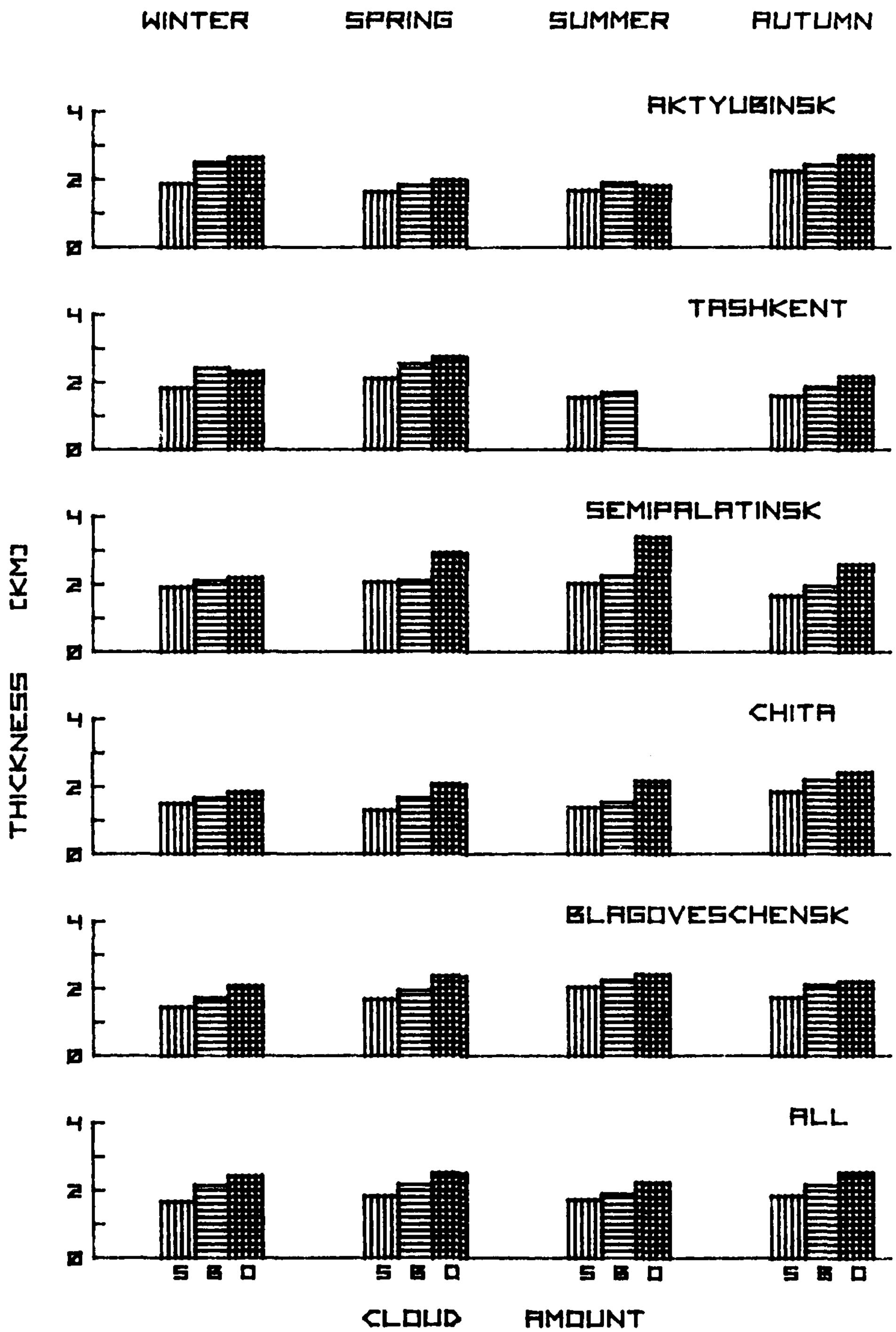

Figure 16b. Seasonal Average Thickness of Cirriform Cloud Layer by Cloud Amount for Aktyubinsk, Tashkent, Semipalatinsk, Chita, Blagoveschensk, and for All Stations

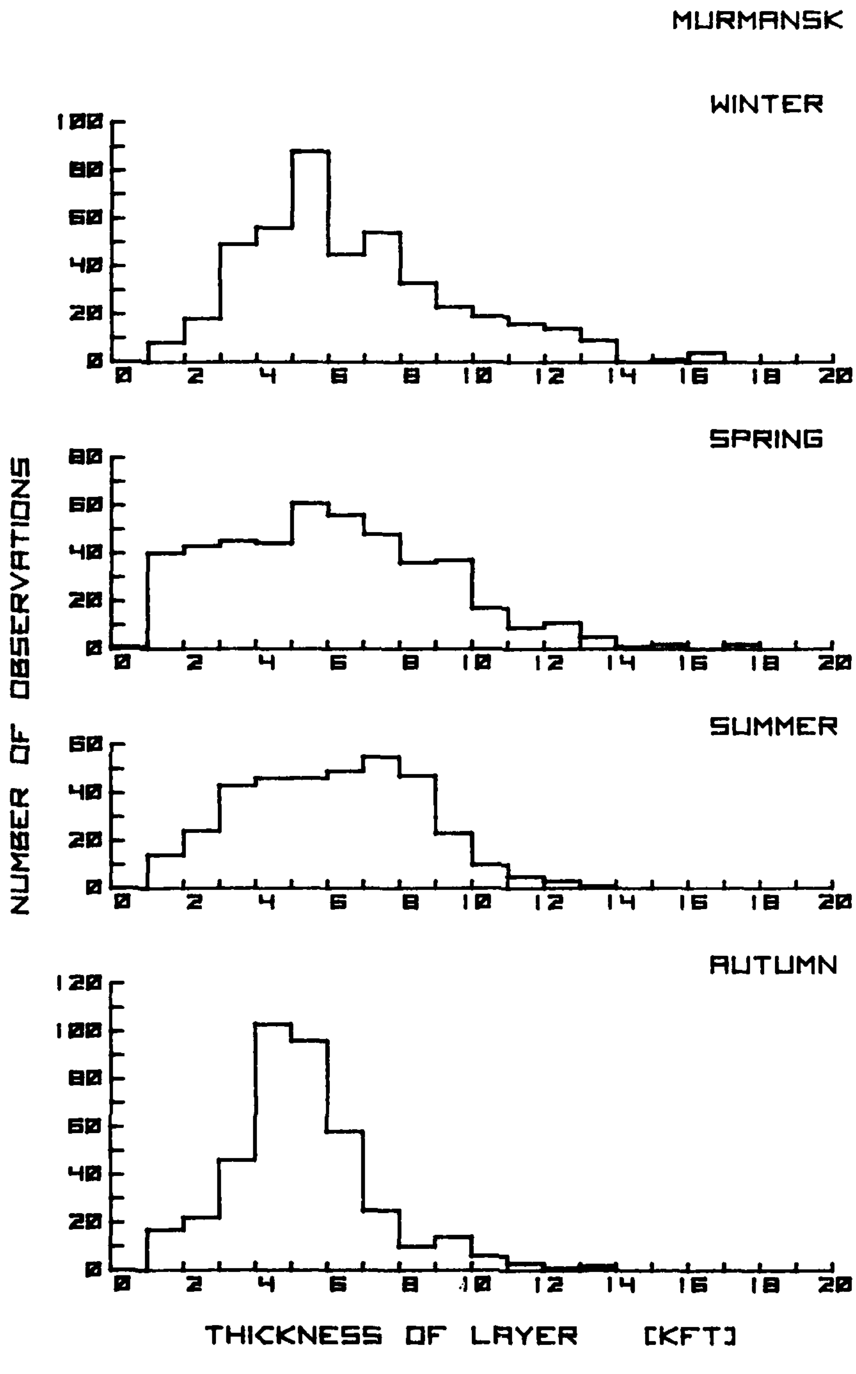

Figure 17a. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Murmansk

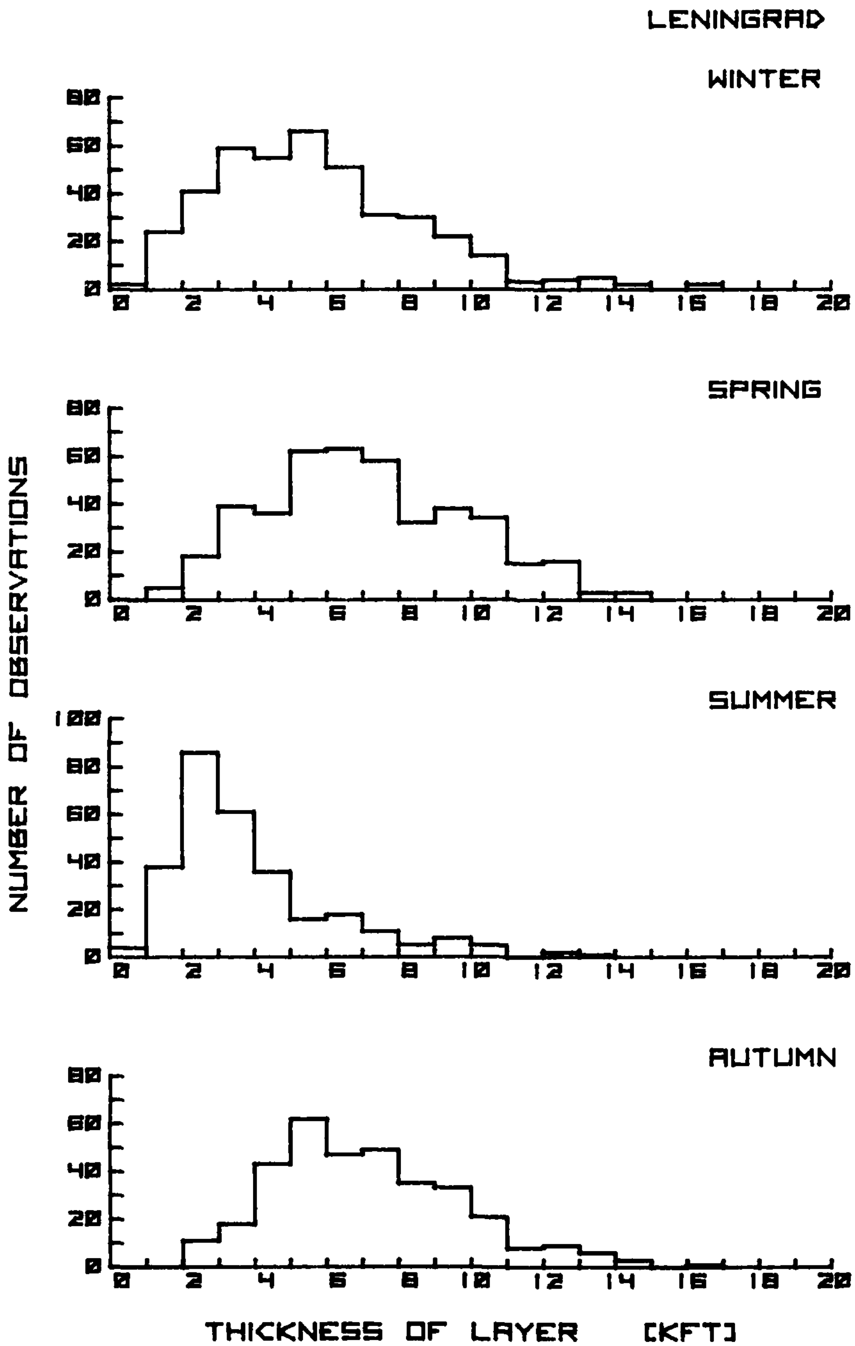

Figure 17b. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Leningrad

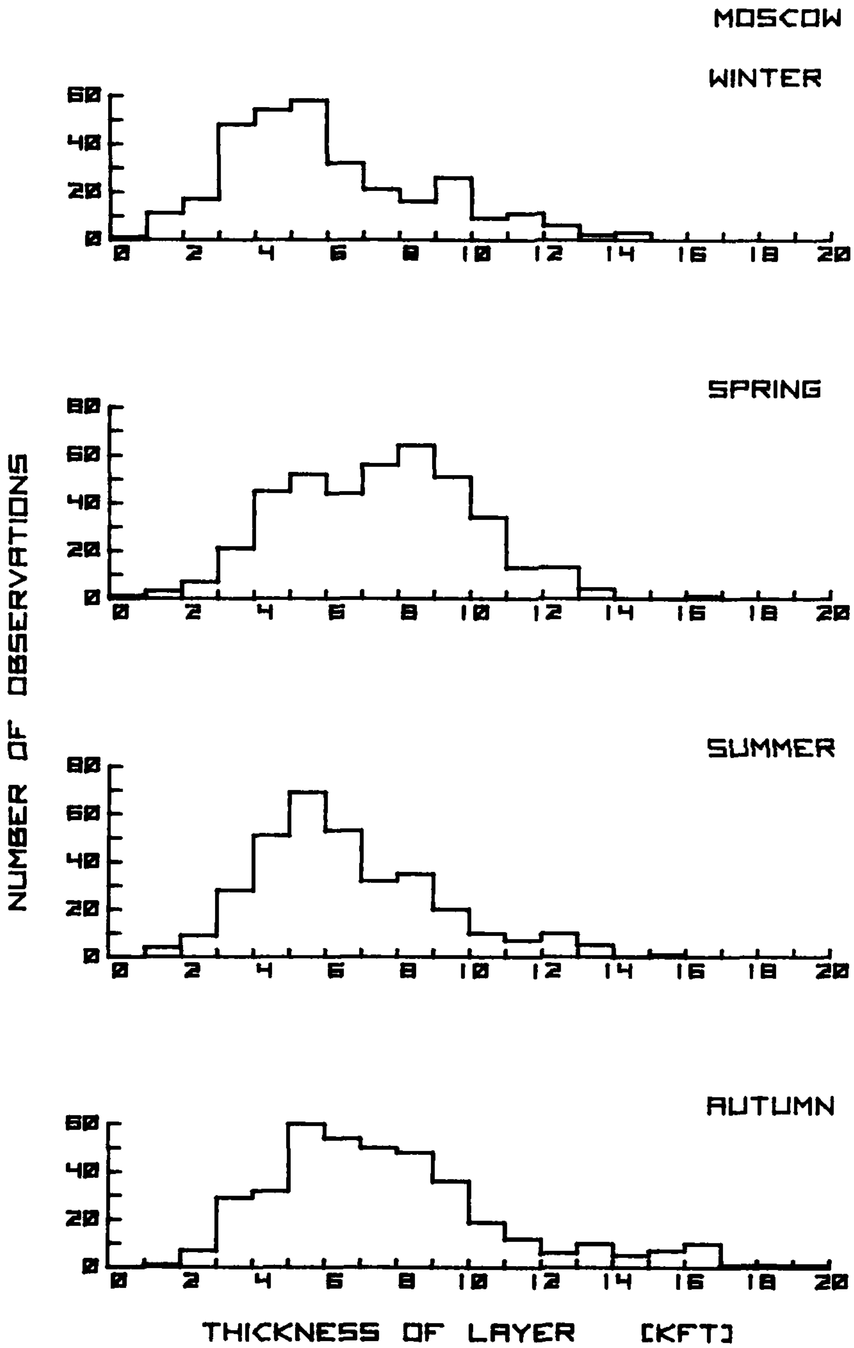

Figure 17c. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Moscow

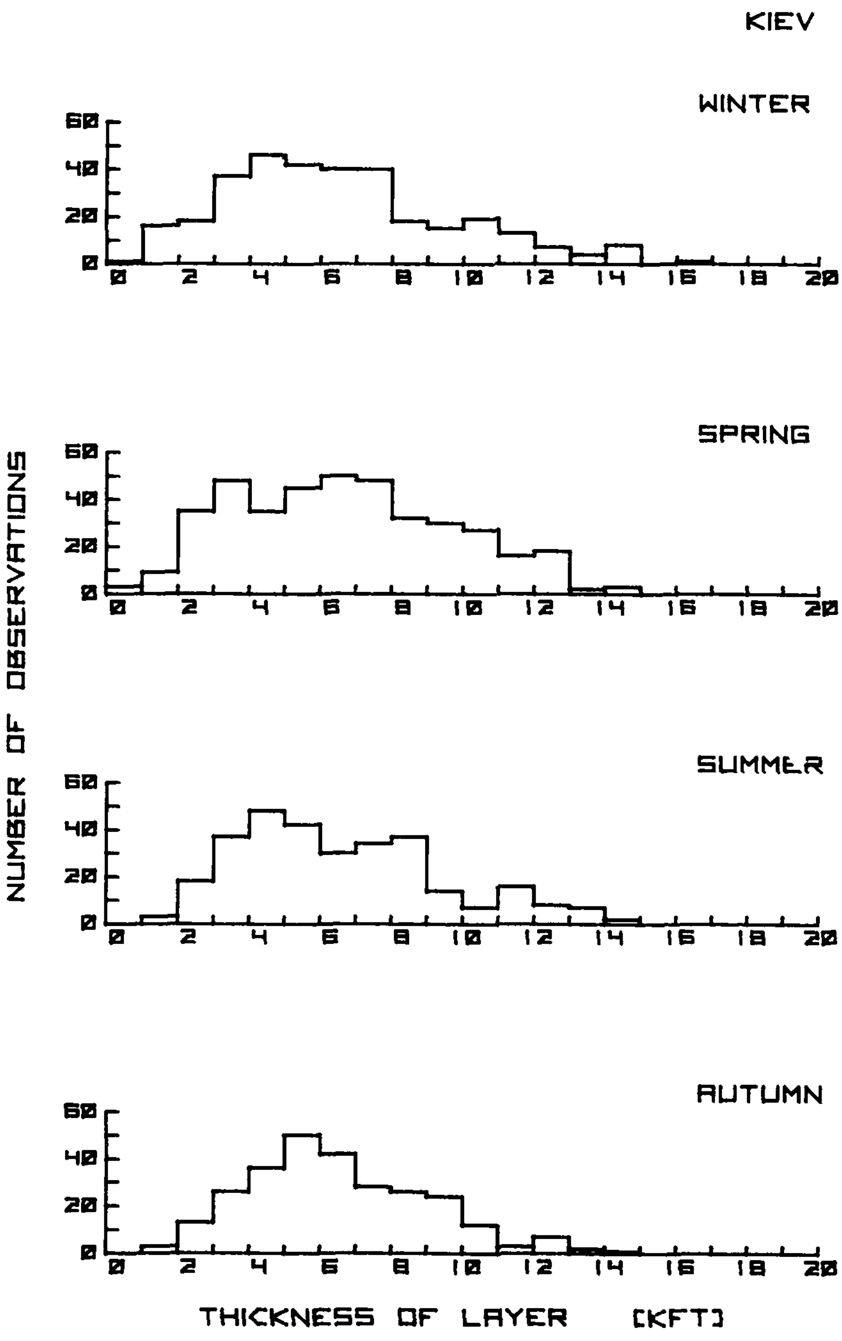

Figure 17d. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Kiev

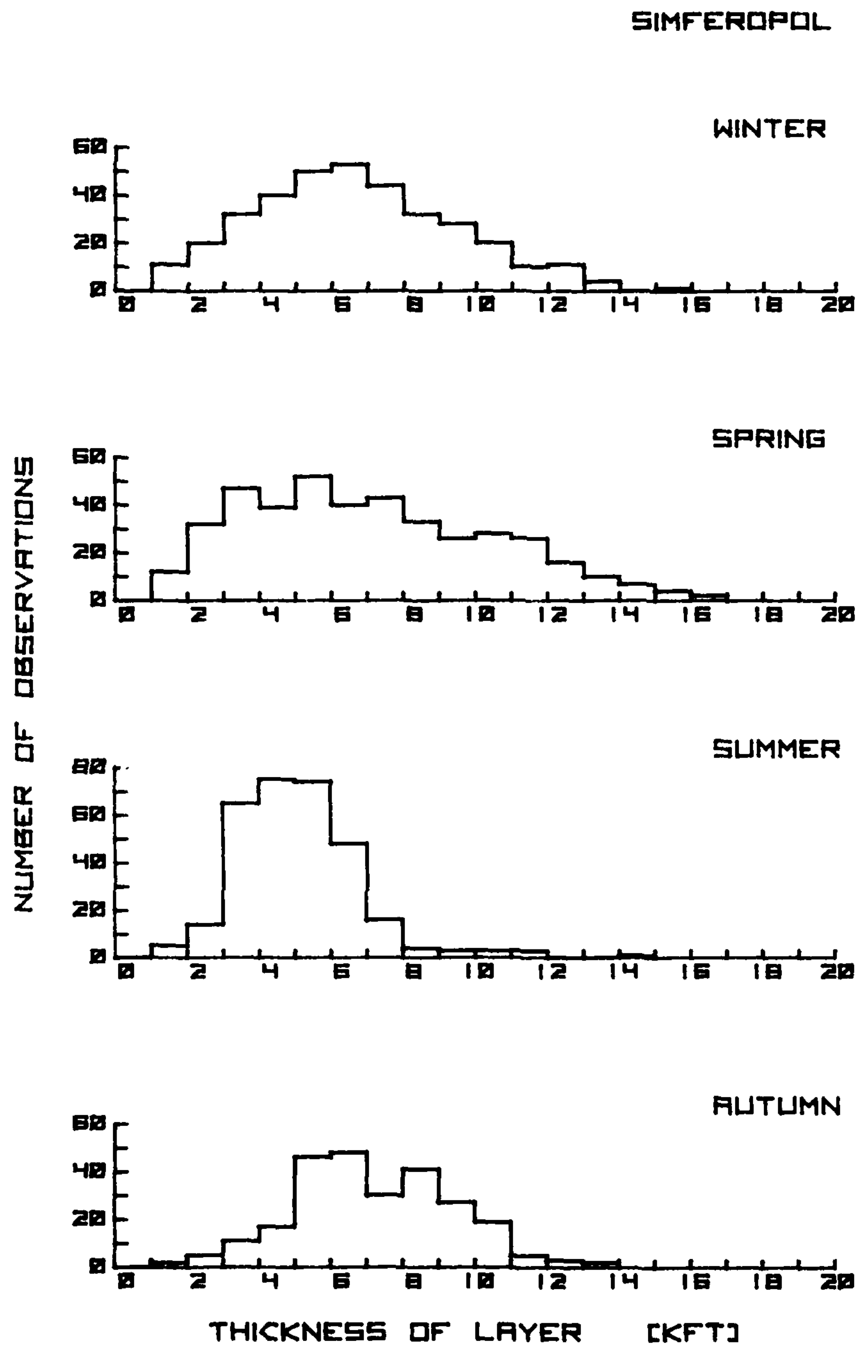

Figure 17e. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Simferopol

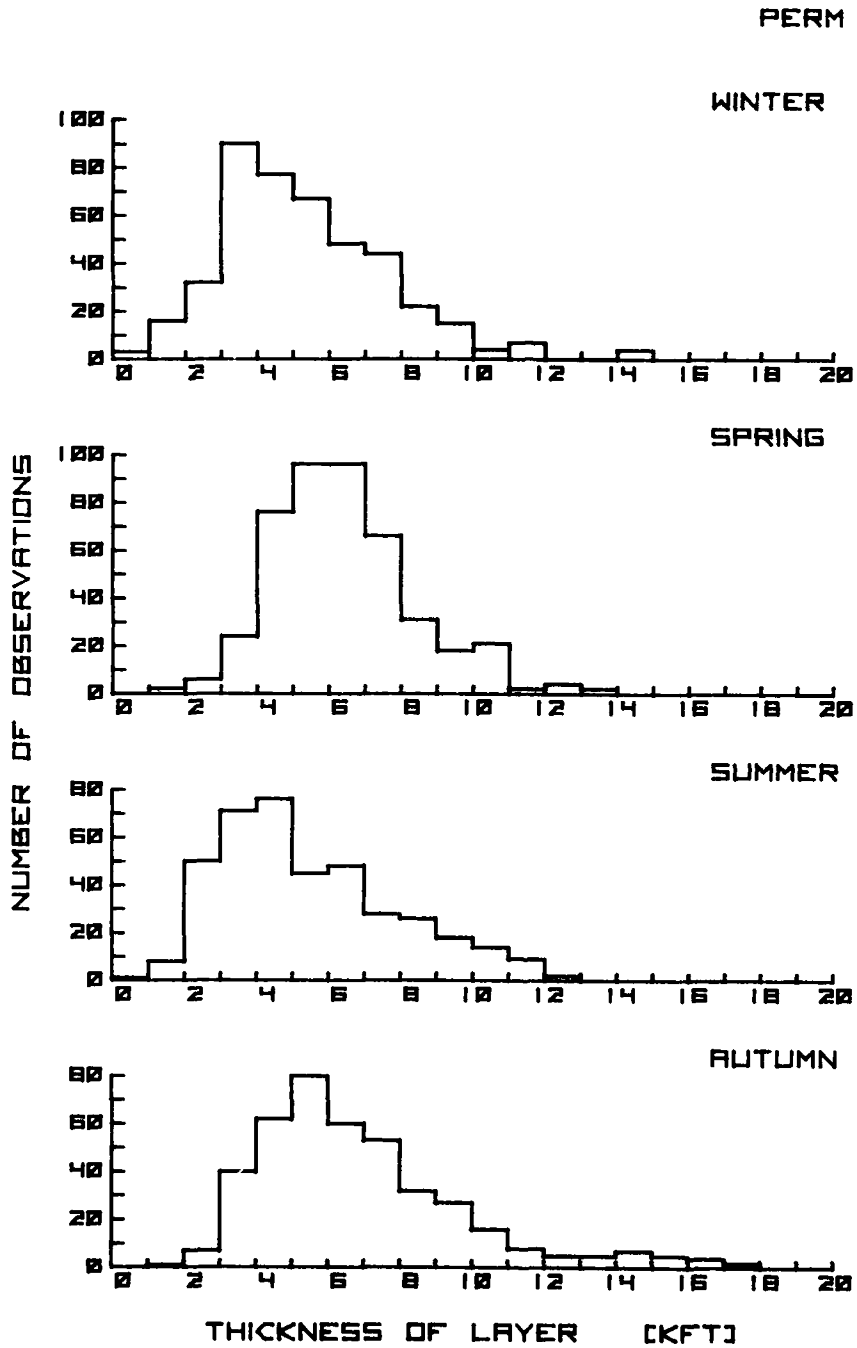

Figure 17f. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Perm

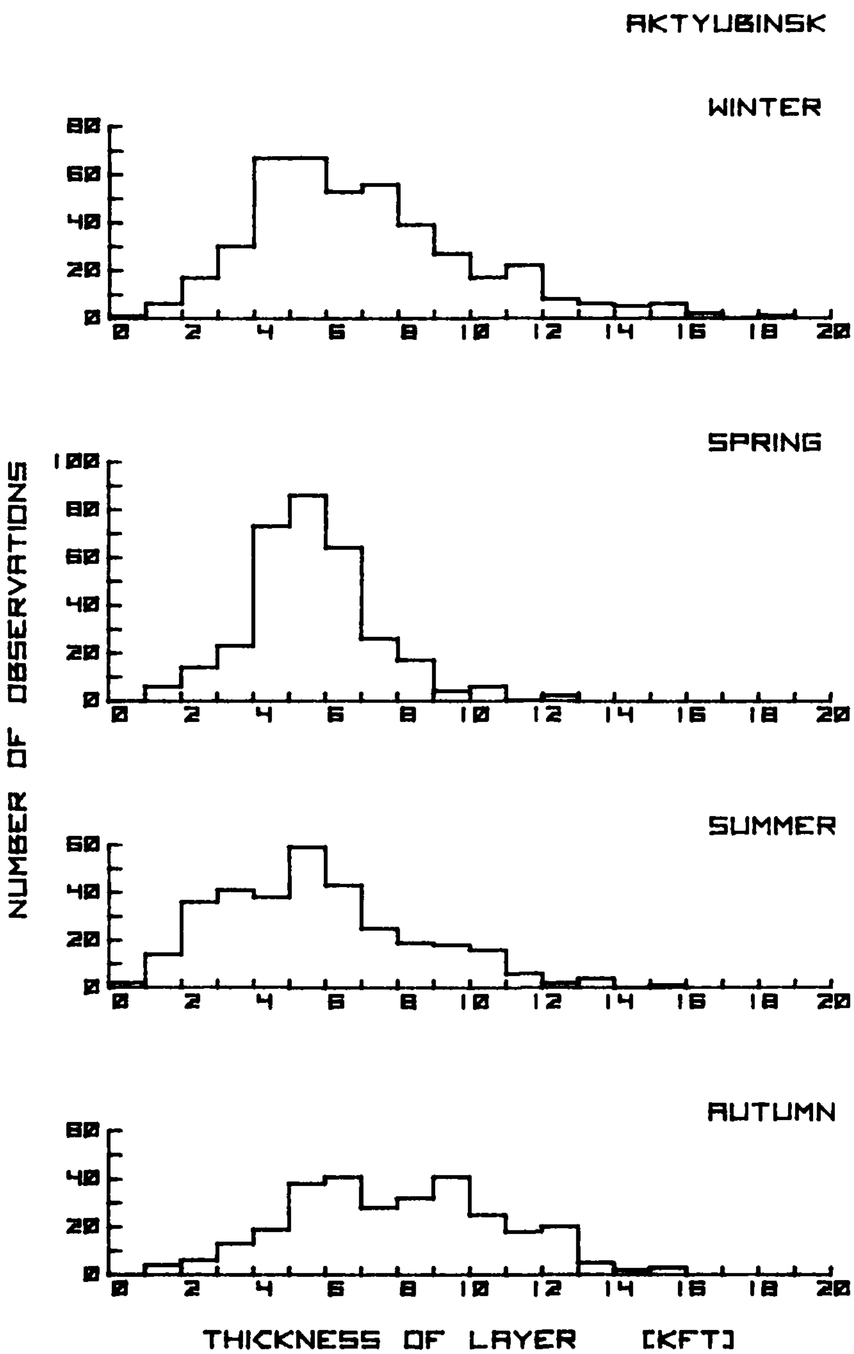

Figure 17g. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Aktyubinsk

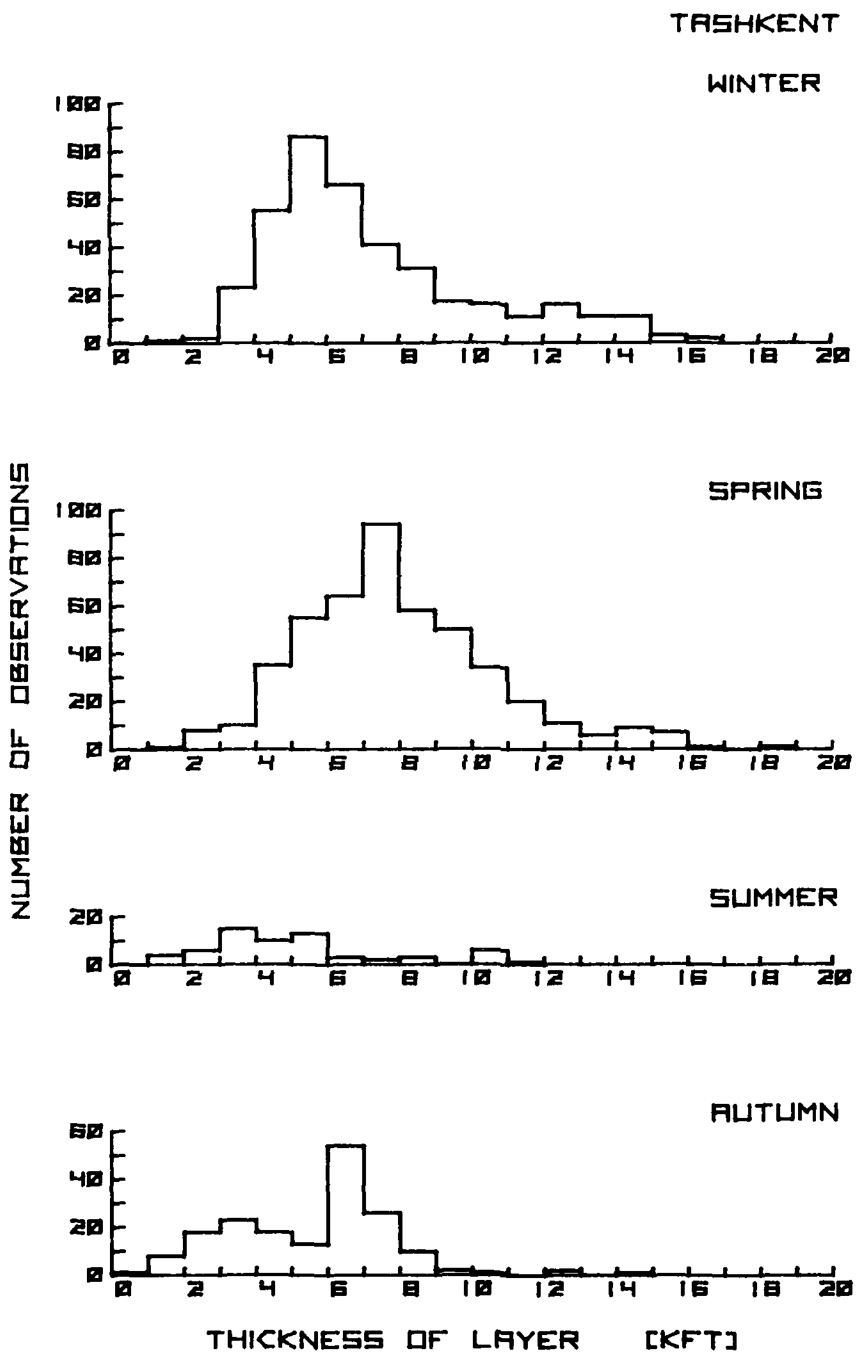

Figure 17h. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Tashkent

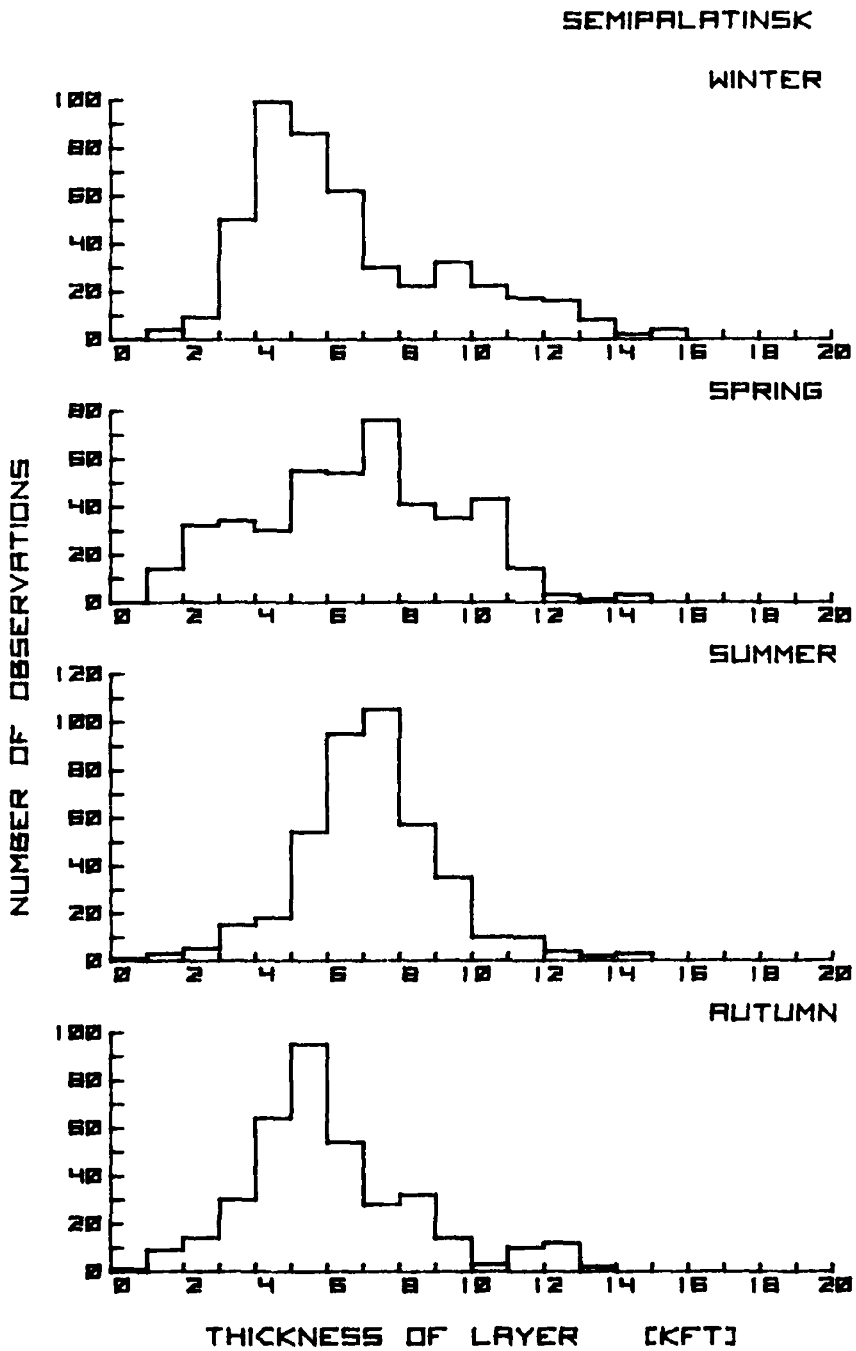

Figure 17i. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Semipalatinsk

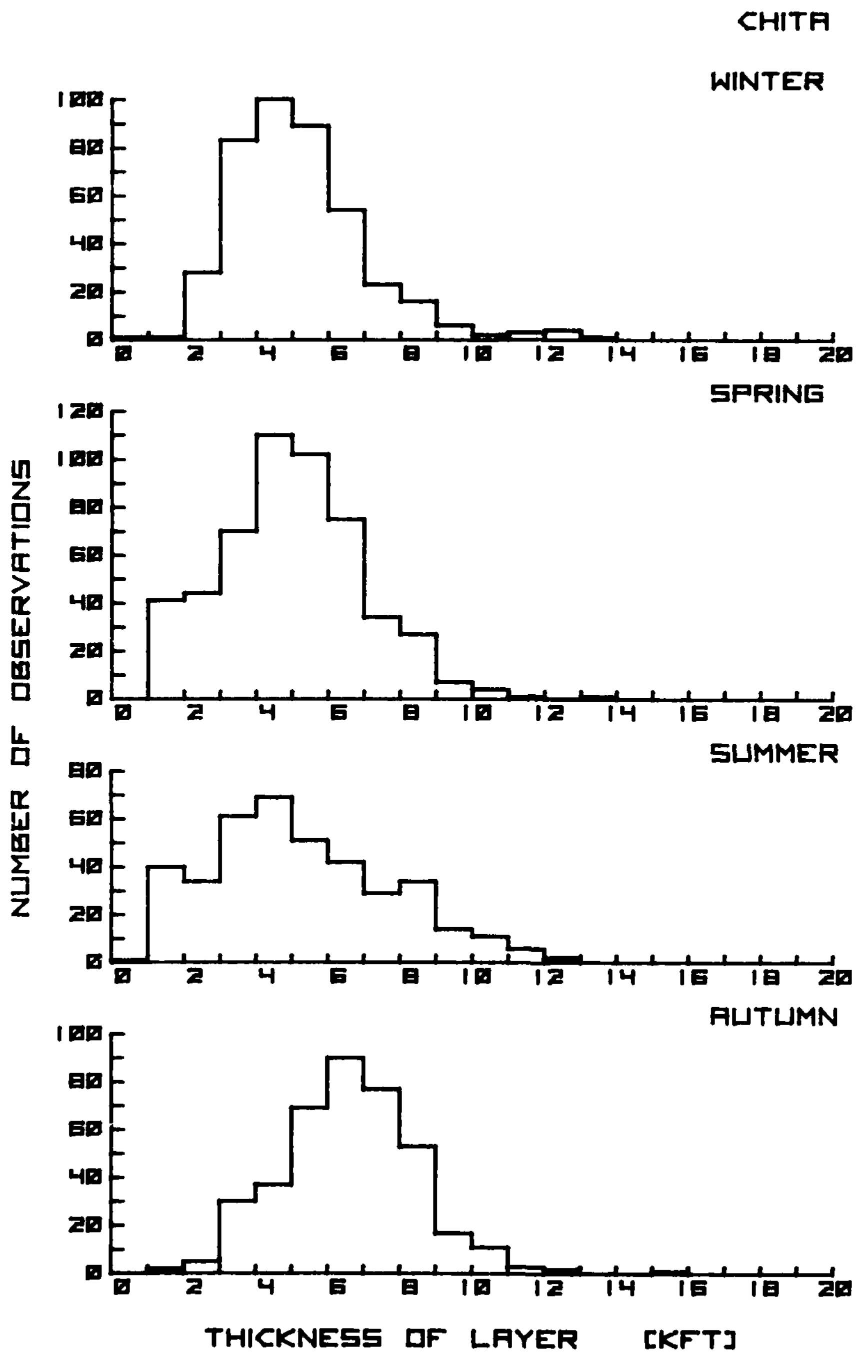

Figure 17j. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Chita

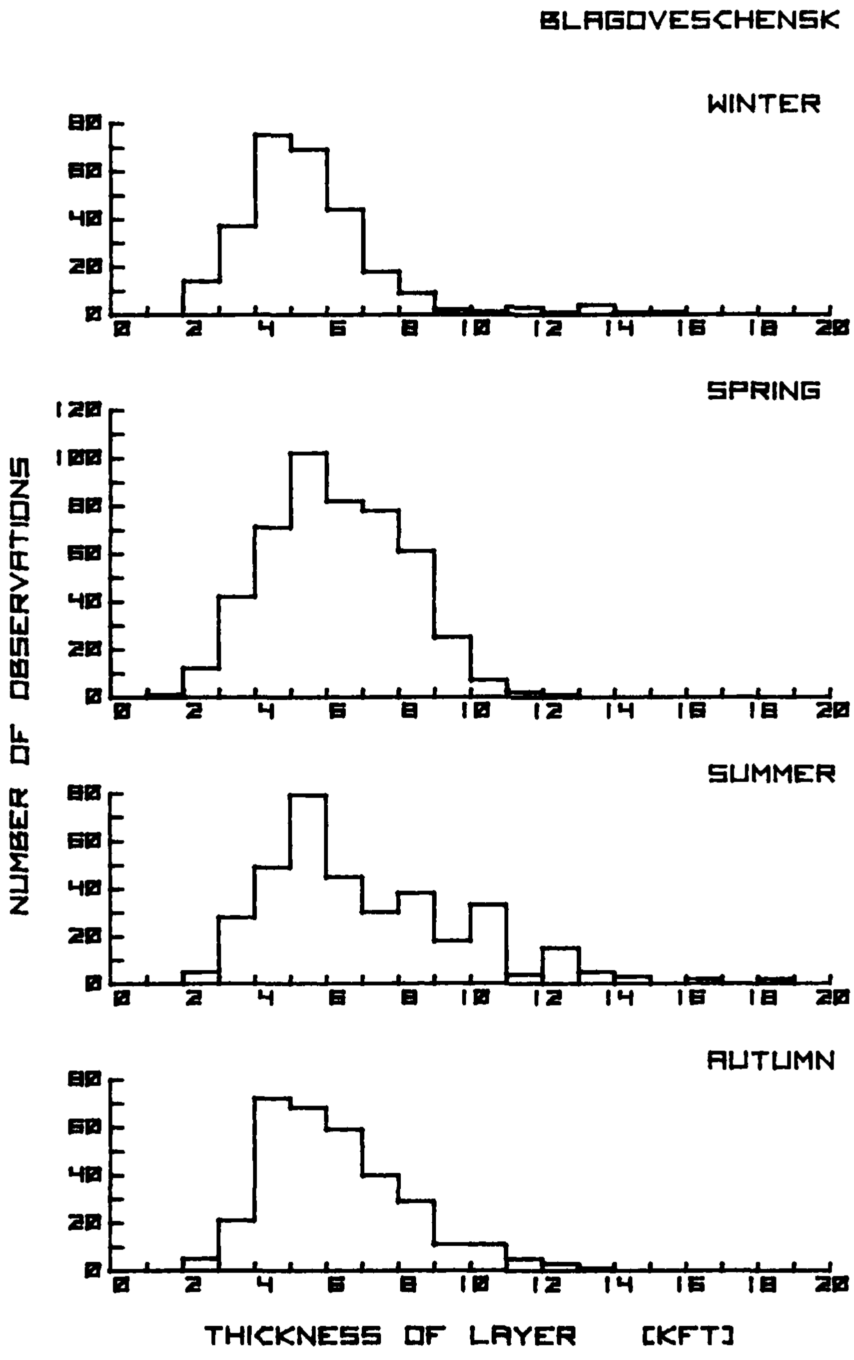

Figure 17k. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at Blagoveschensk

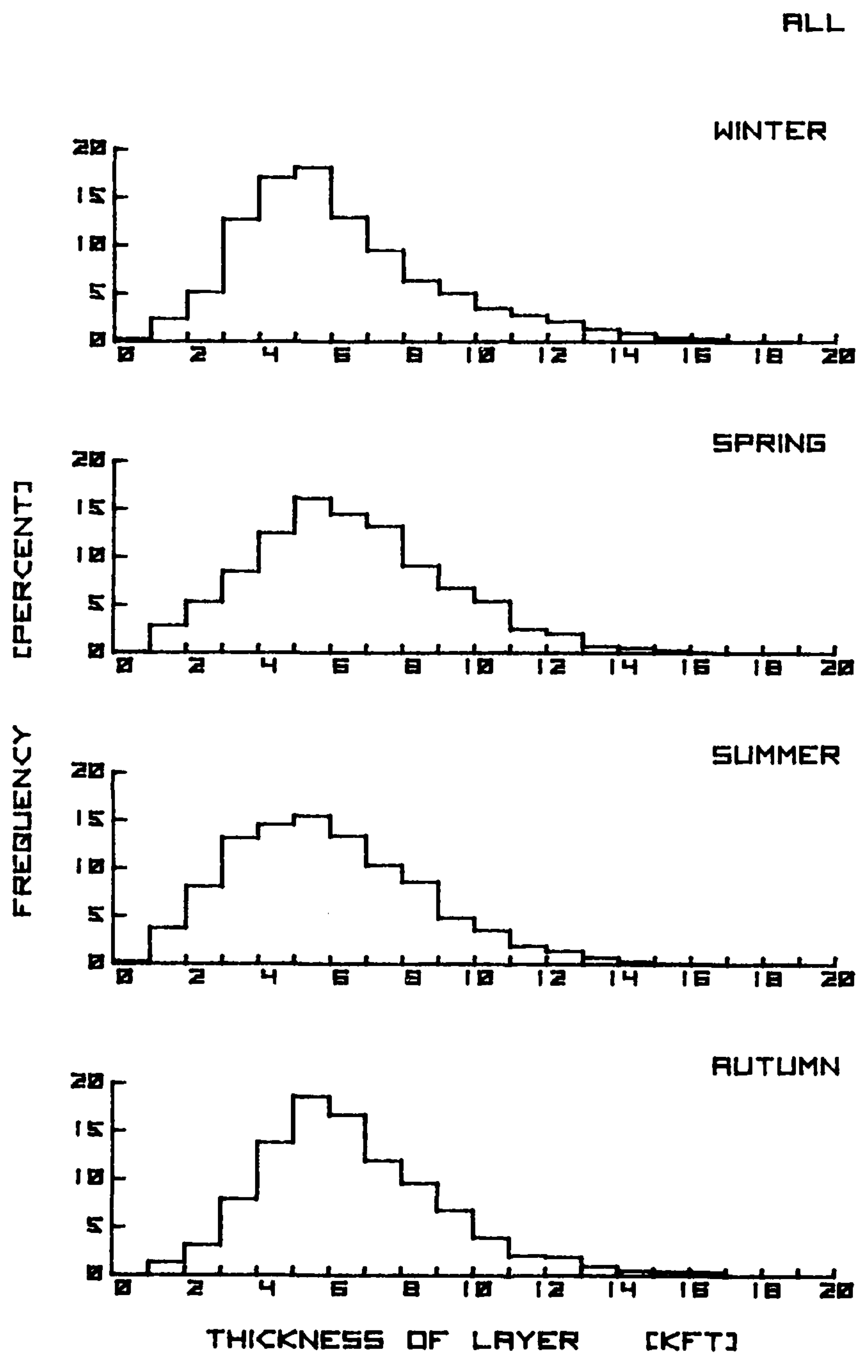

Figure 17 ℓ. Seasonal Frequency Distribution of Cirriform Cloud Layer Thickness at All Stations

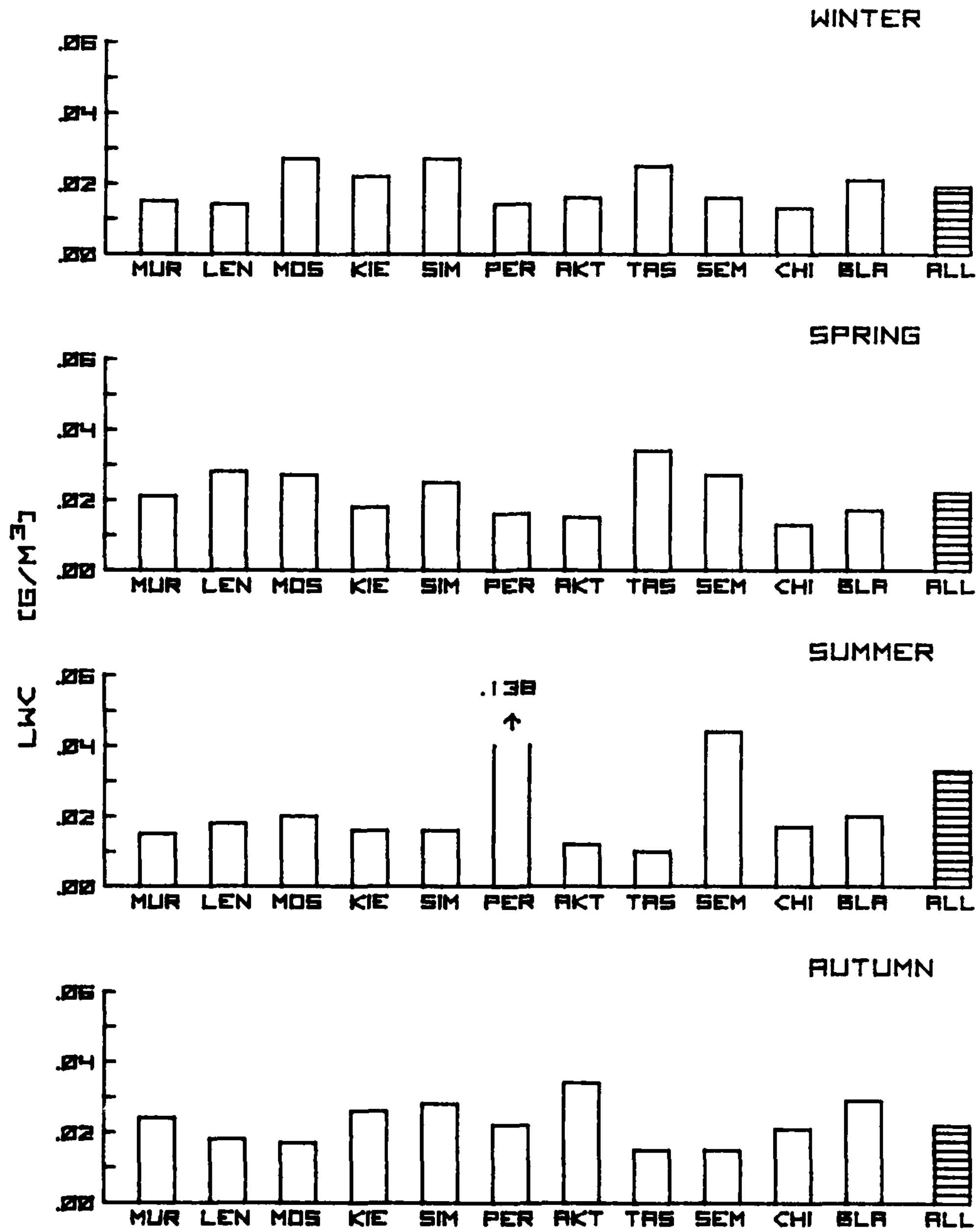

Figure 18. Seasonal Average Liquid Water Content Values of Cirriform Cloud Layers

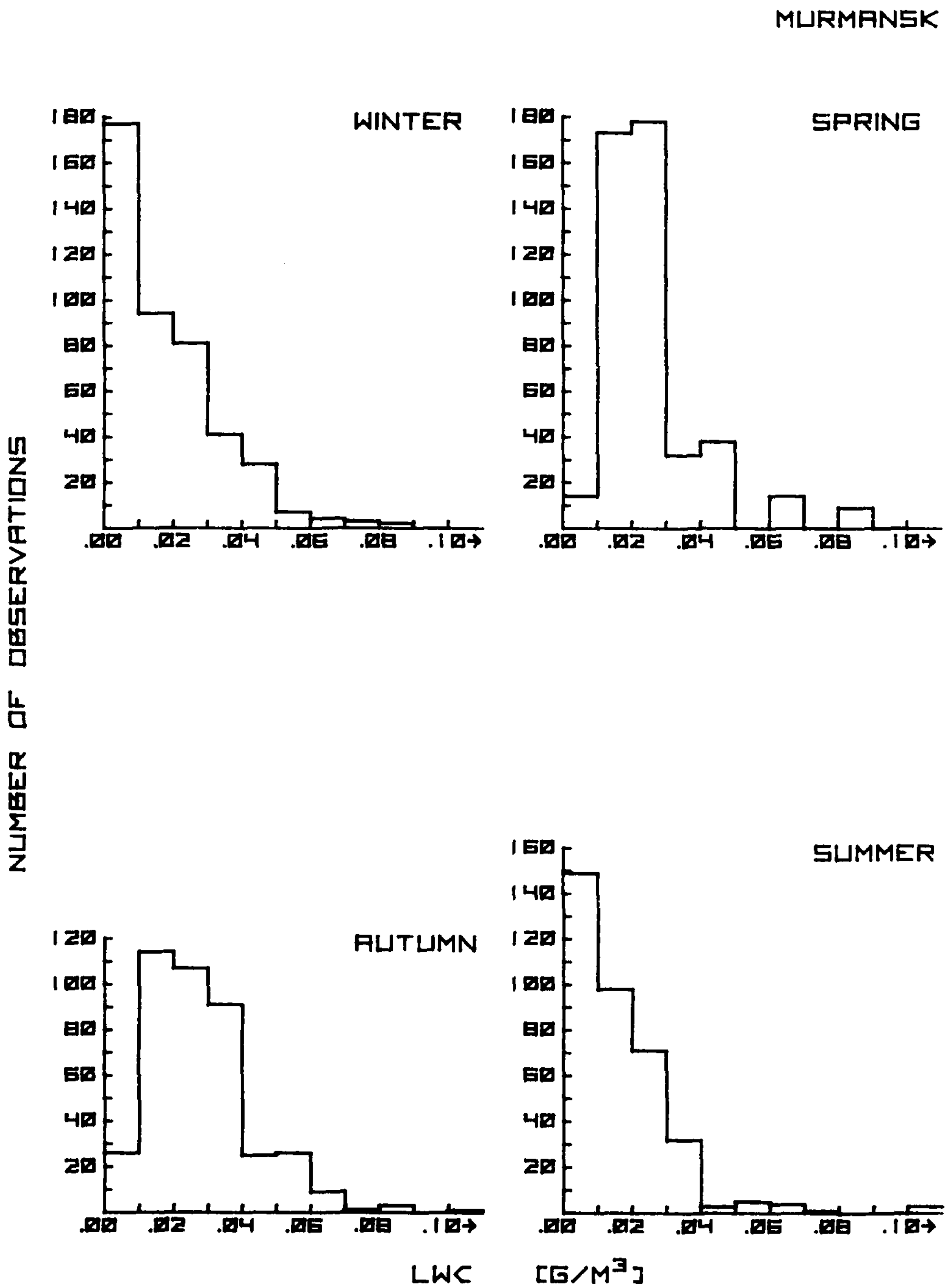

Figure 19a. Seasonal Frequency Distribution of Liquid Water Content for Murmansk

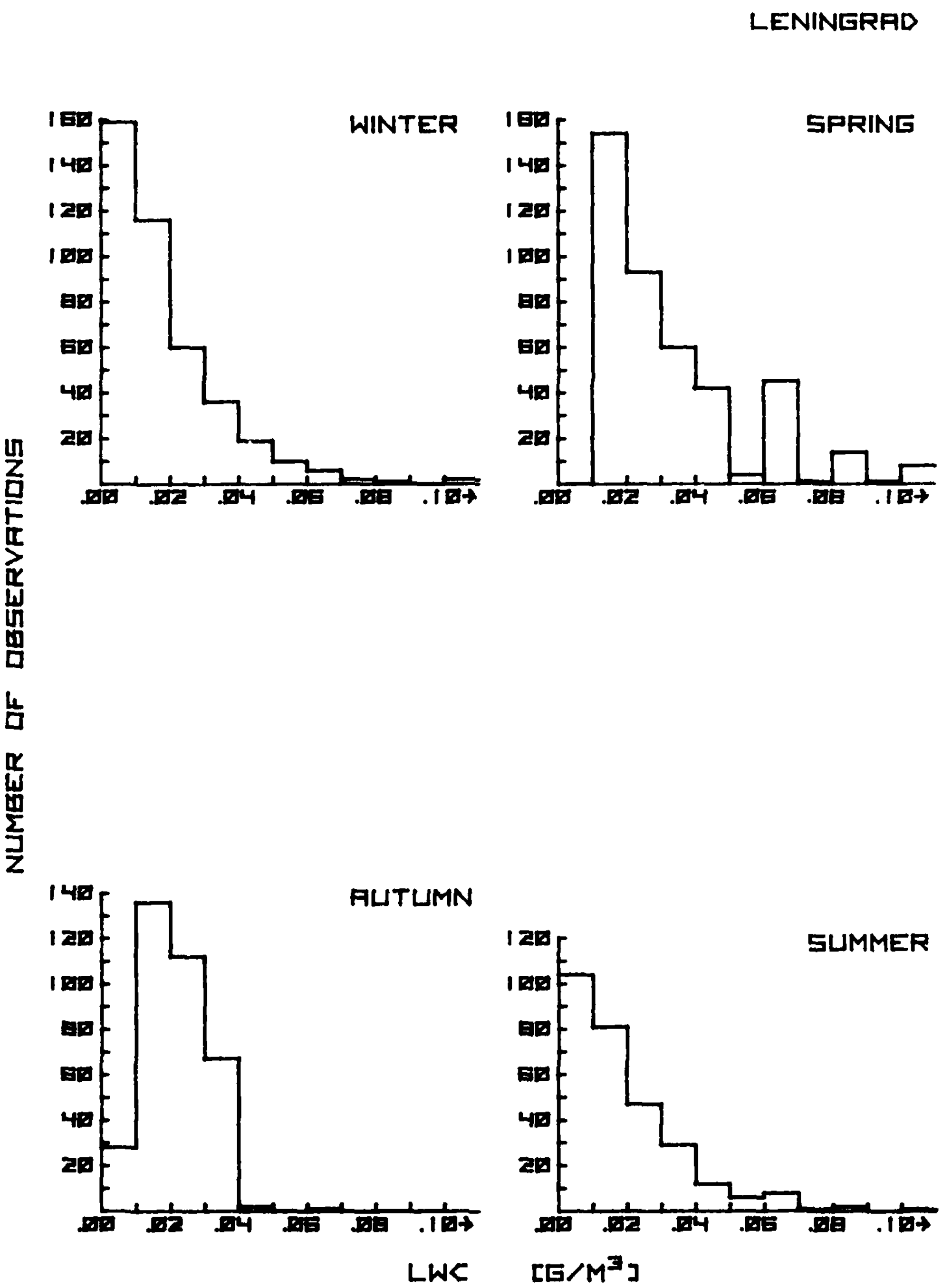

Figure 19b. Seasonal Frequency Distribution of Liquid Water Content for Leningrad

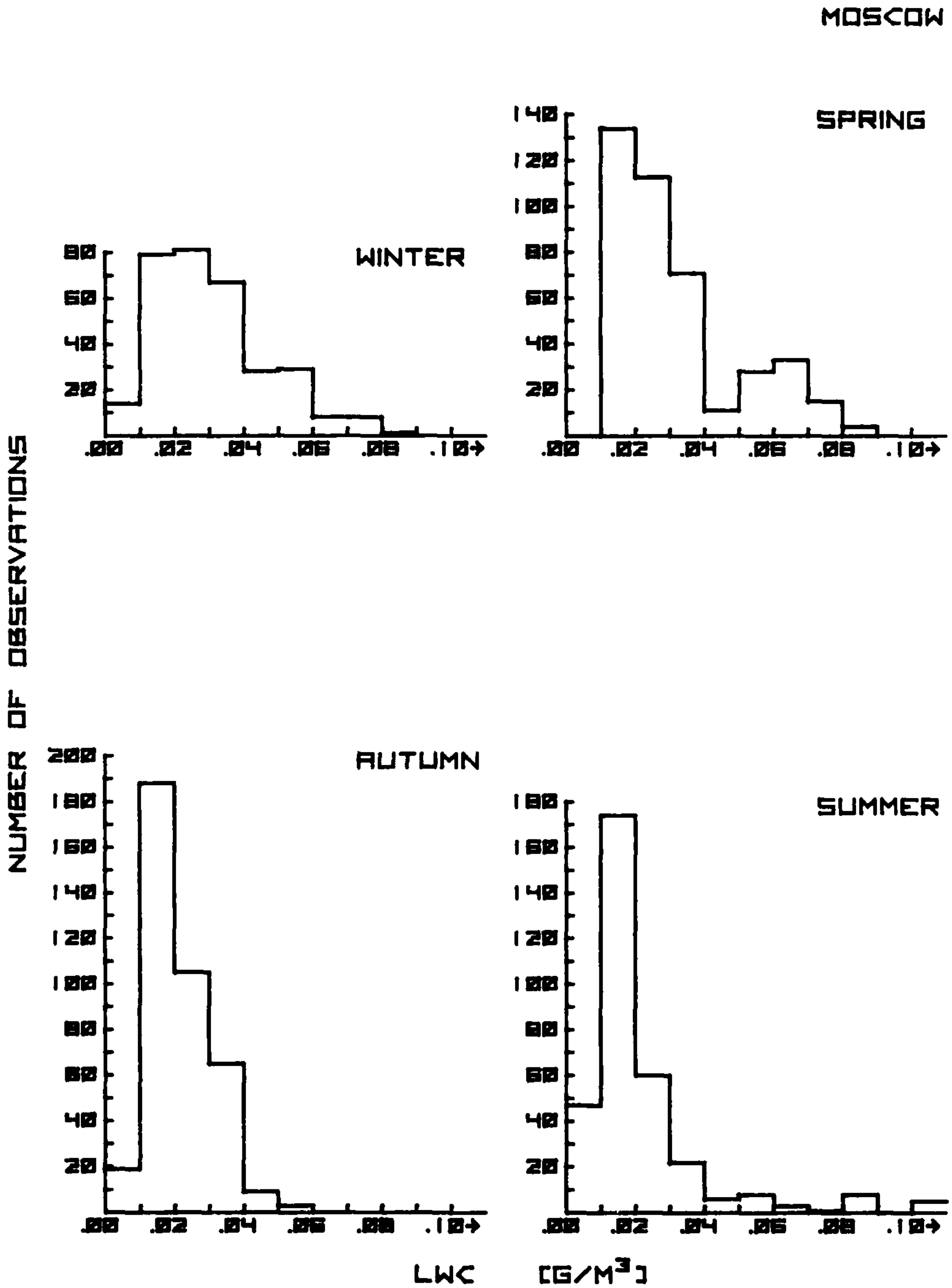

Figure 19c. Seasonal Frequency Distribution of Liquid Water Content for Moscow

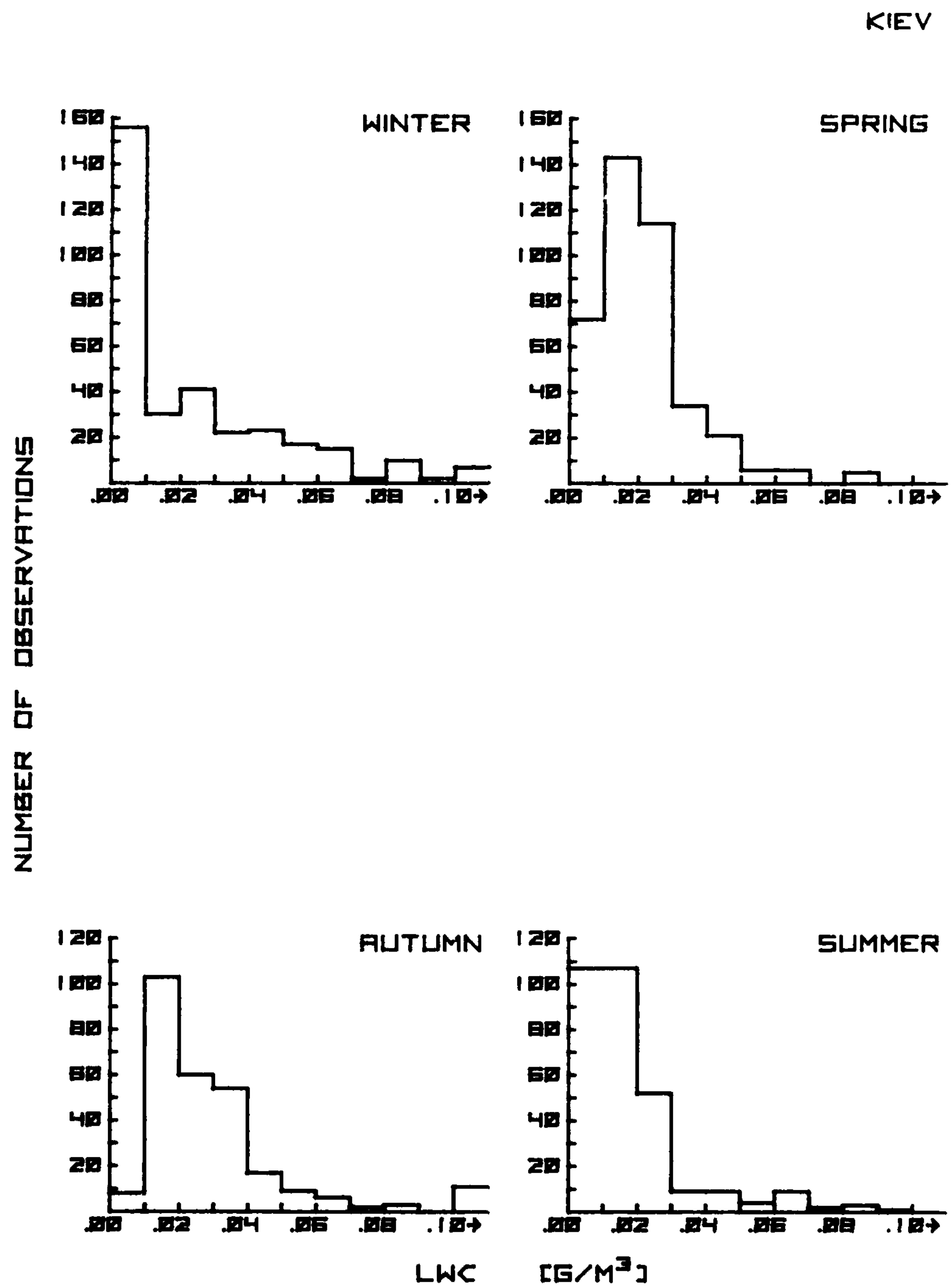

Figure 19d. Seasonal Frequency Distribution of Liquid Water Content for Kiev

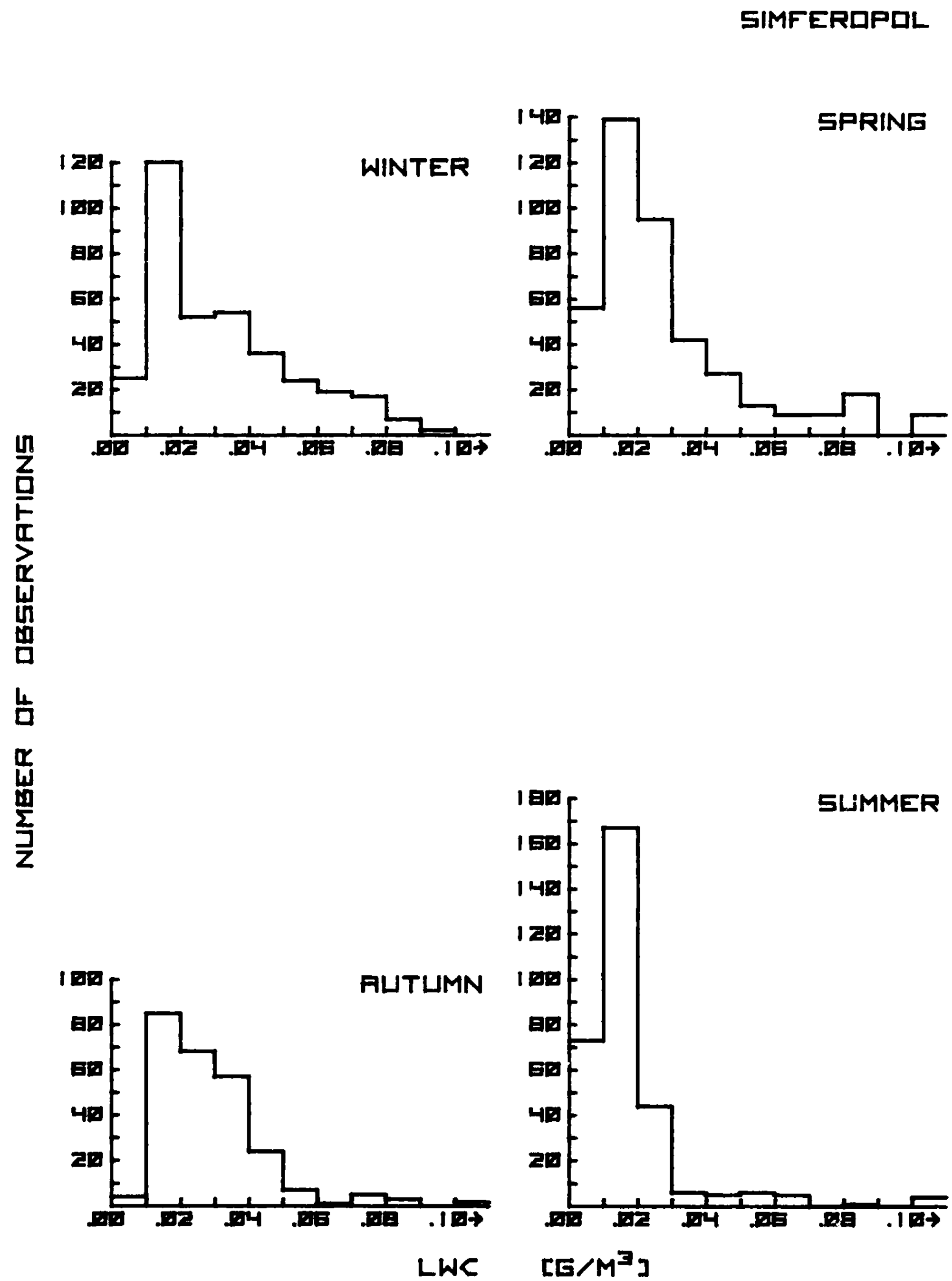

Figure 19e. Seasonal Frequency Distribution of Liquid Water Content for Simferopol

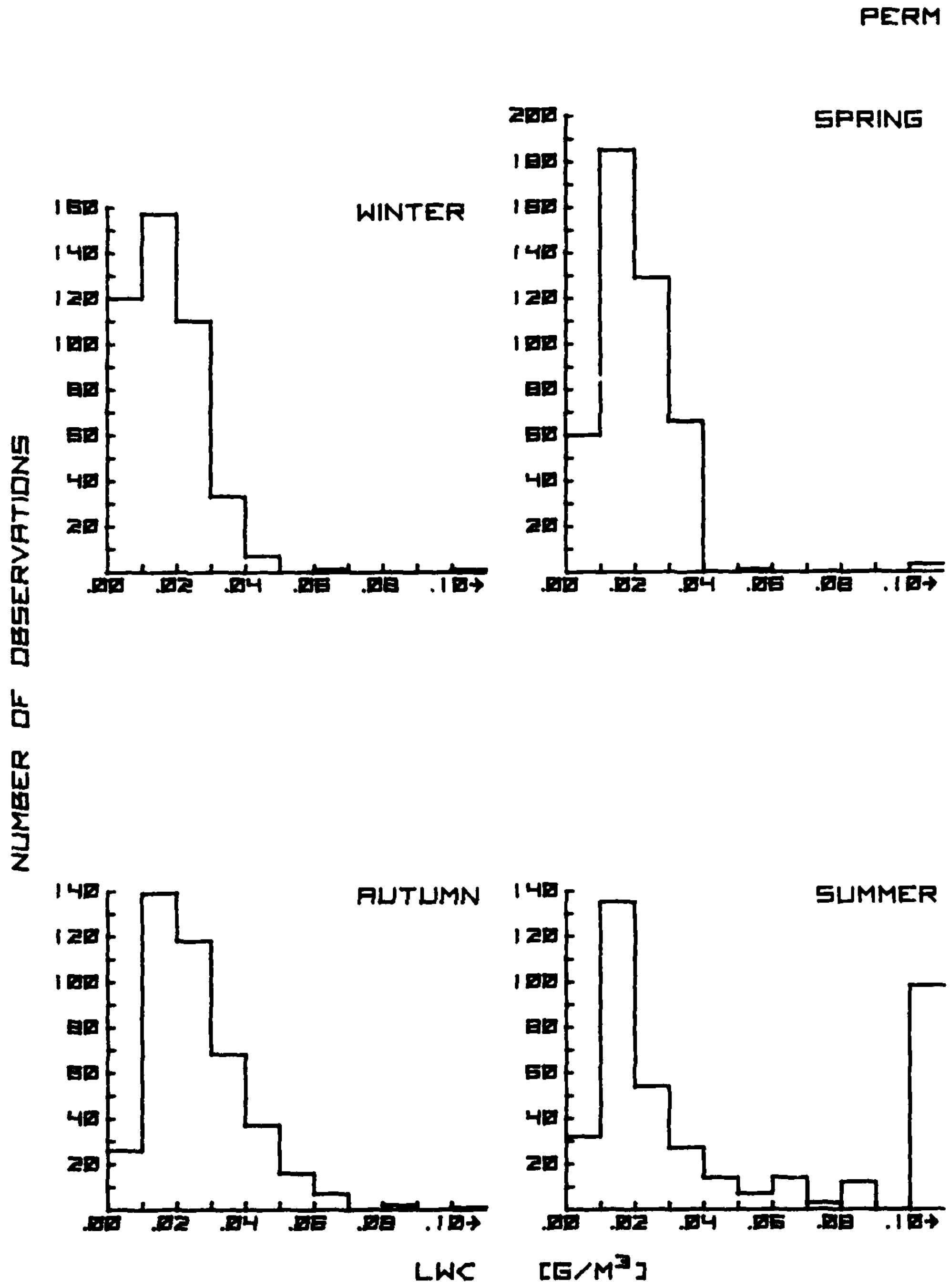

Figure 19f. Seasonal Frequency Distribution of Liquid Water Content for Perm

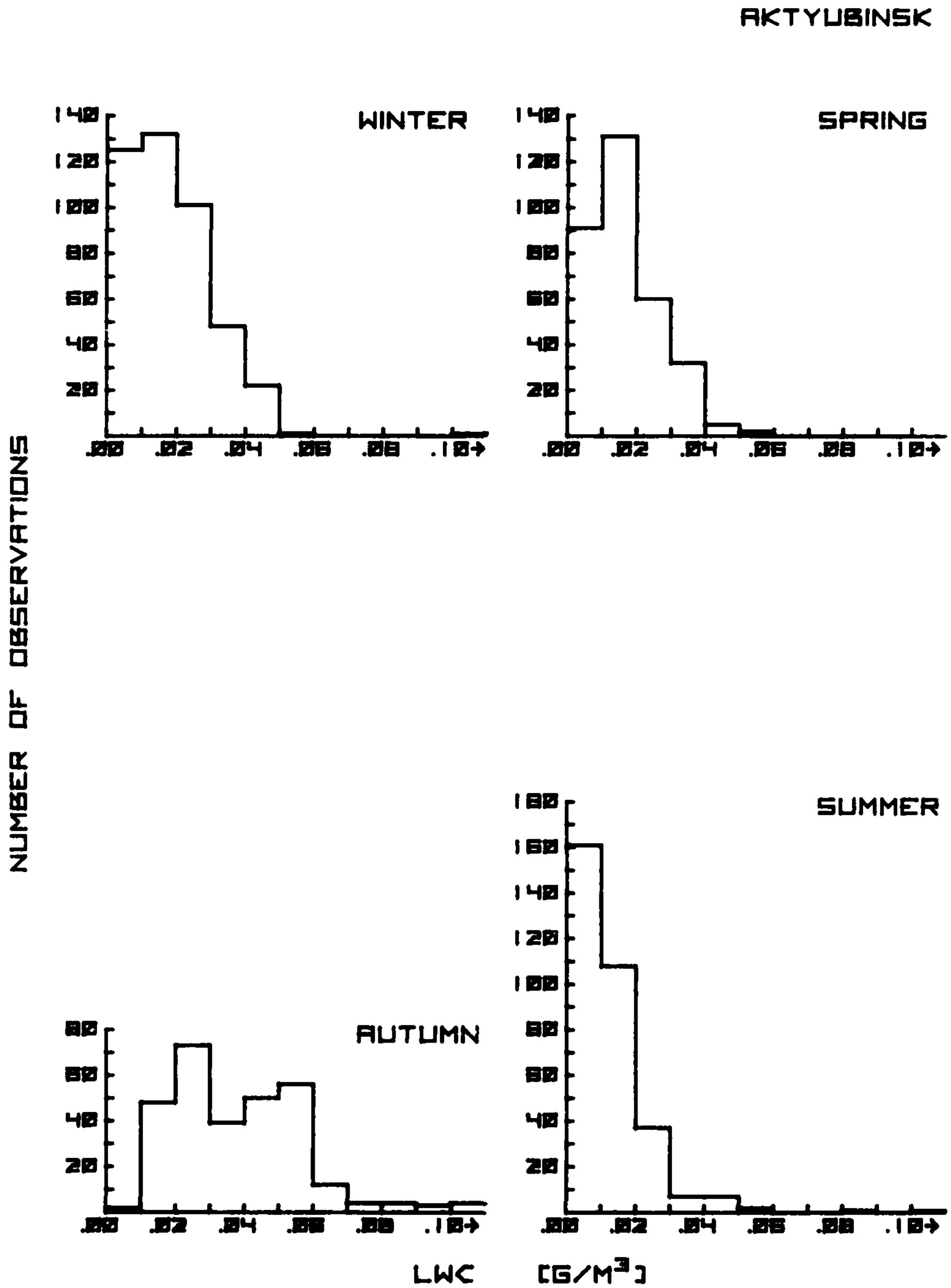

Figure 19g. Seasonal Frequency Distribution of Liquid Water C ontent for Aktyubinsk

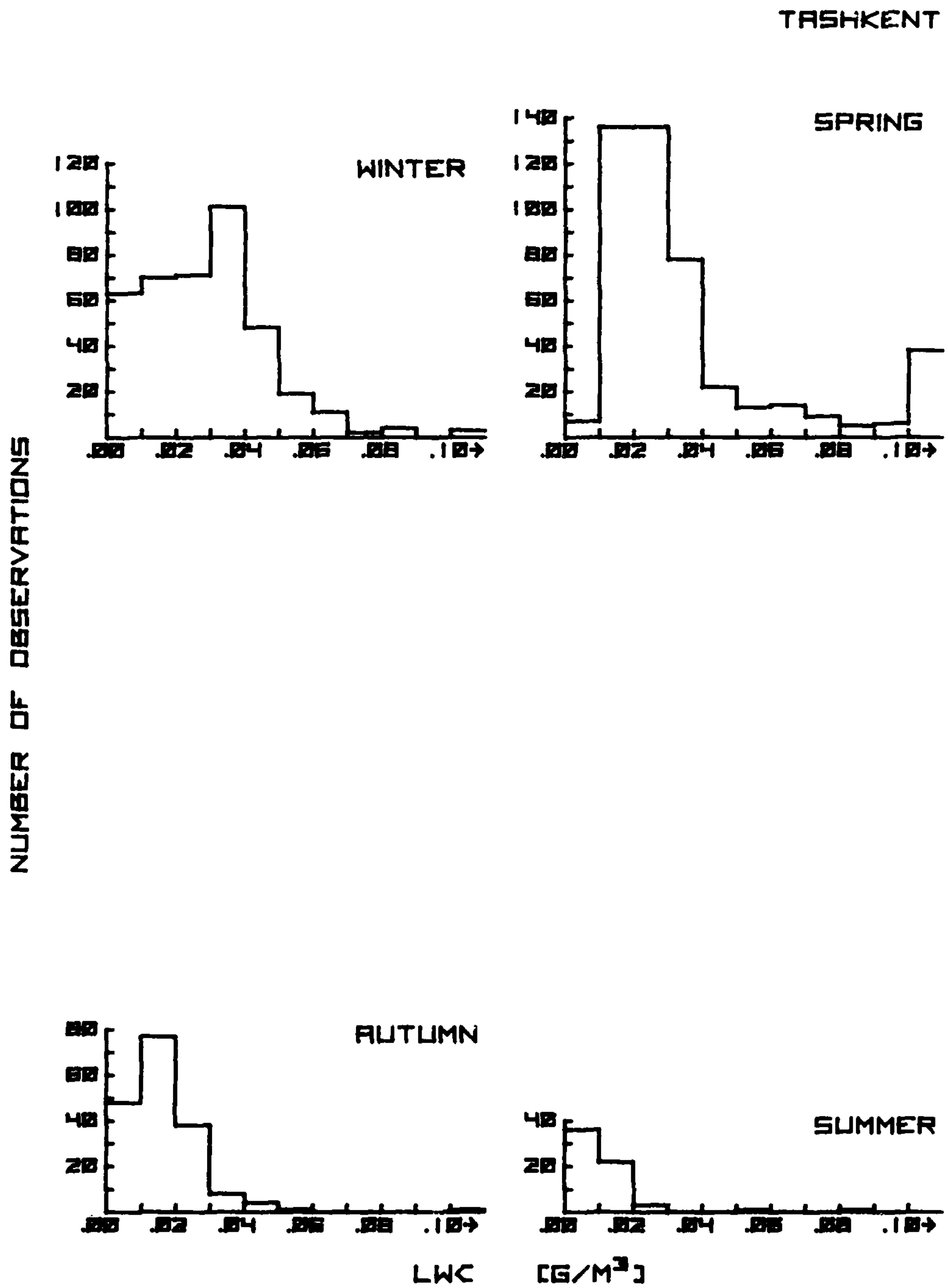

Figure 19h. Seasonal Frequency Distribution of Liquid Water Content for Tashkent

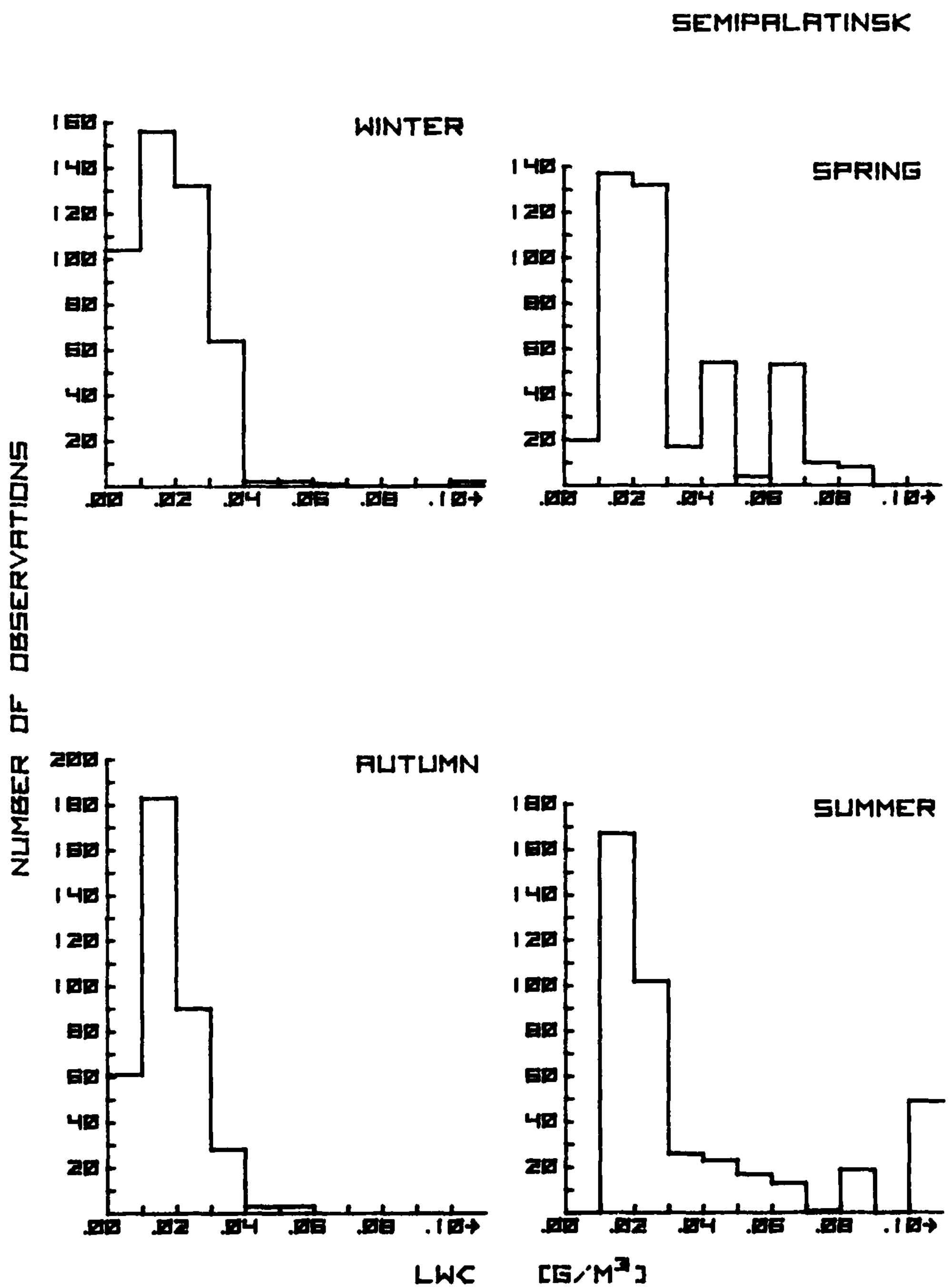

Figure 19i. Seasonal Frequency Distribution of Liquid Water Content for Semipalatinsk

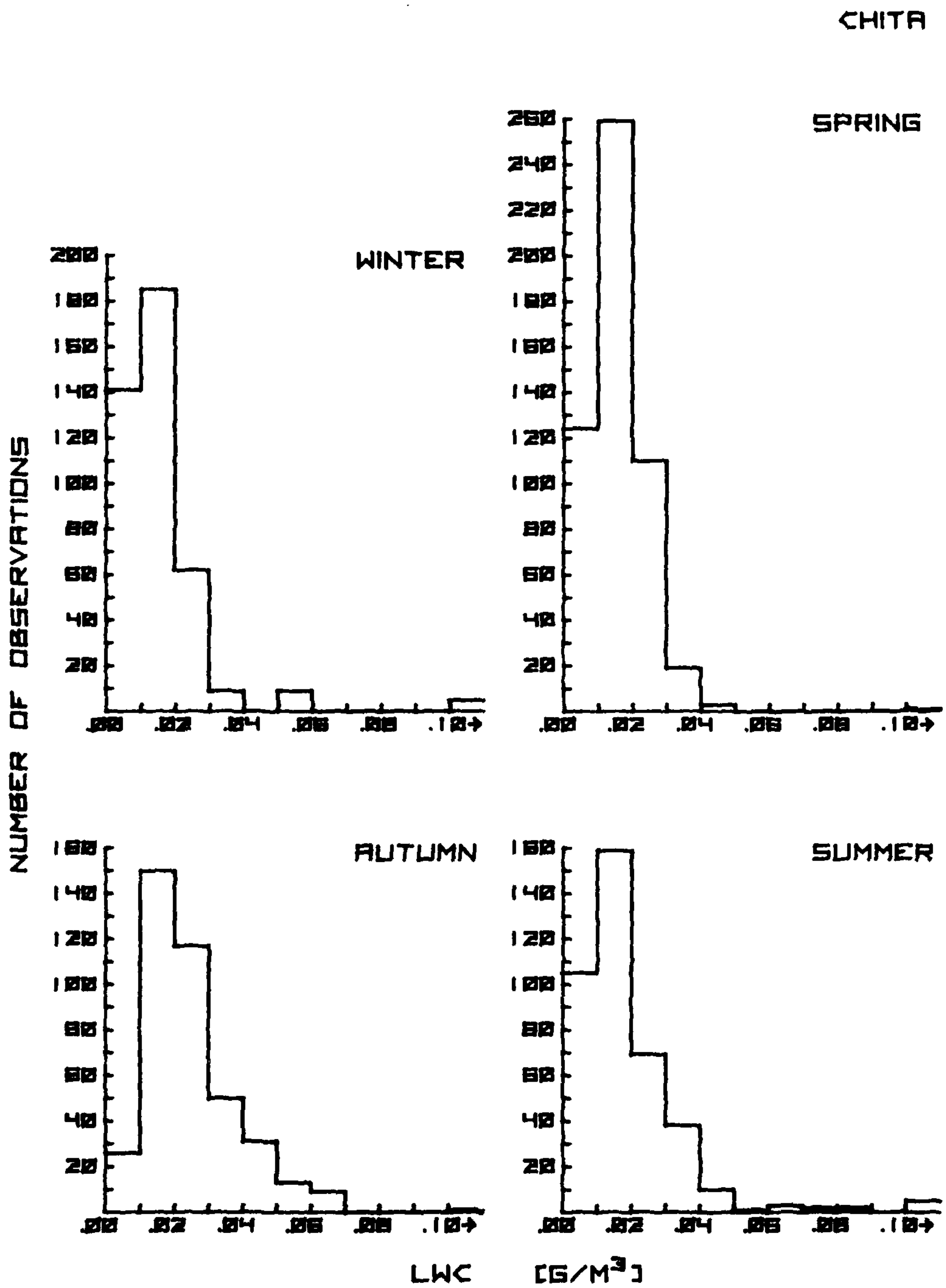

Figure 19j. Seasonal Frequency Distribution of Liquid Water Content for Chita

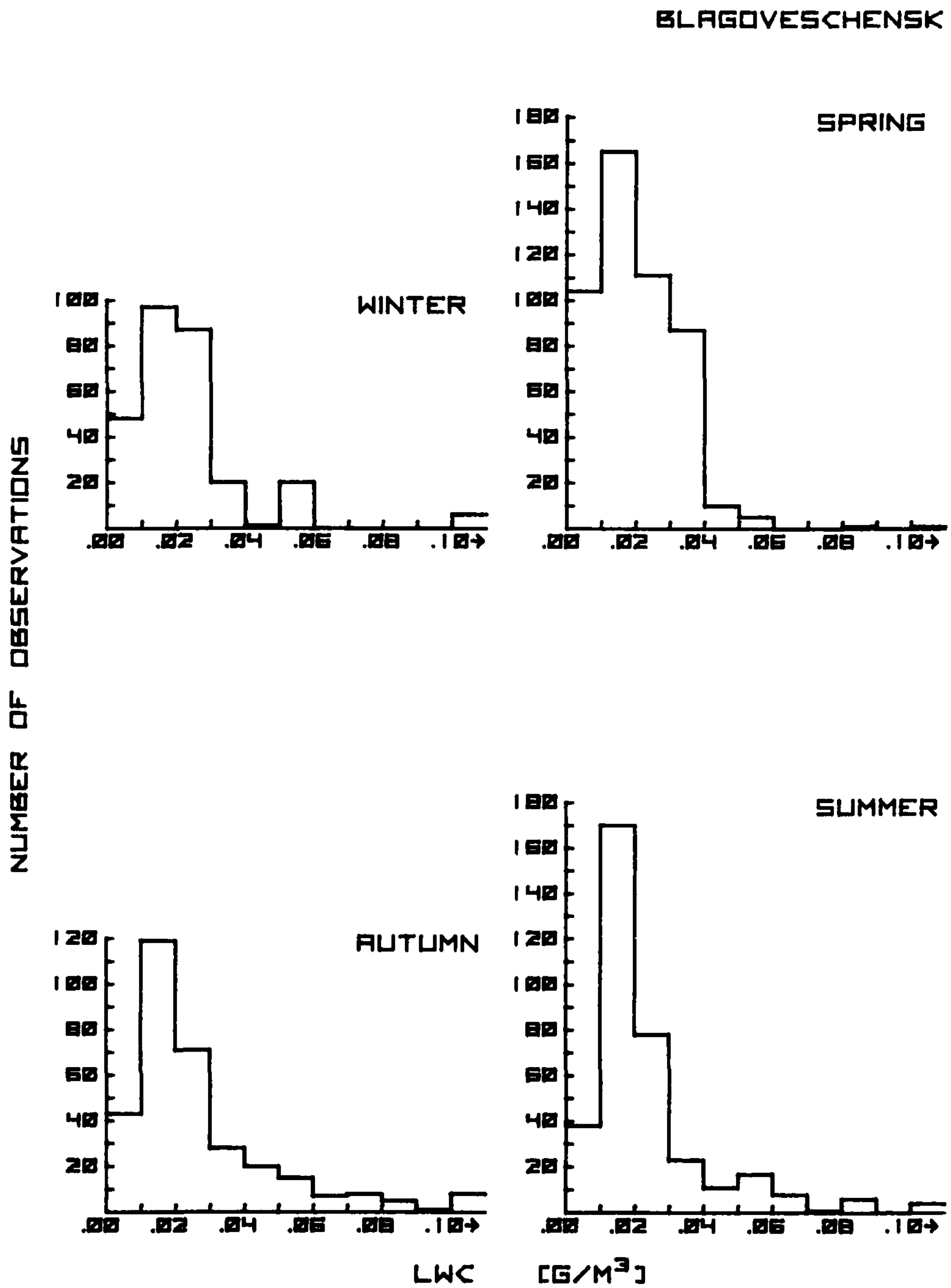

Figure 19k. Seasonal Frequency Distribution of Liquid Water Content for Blagoveschensk

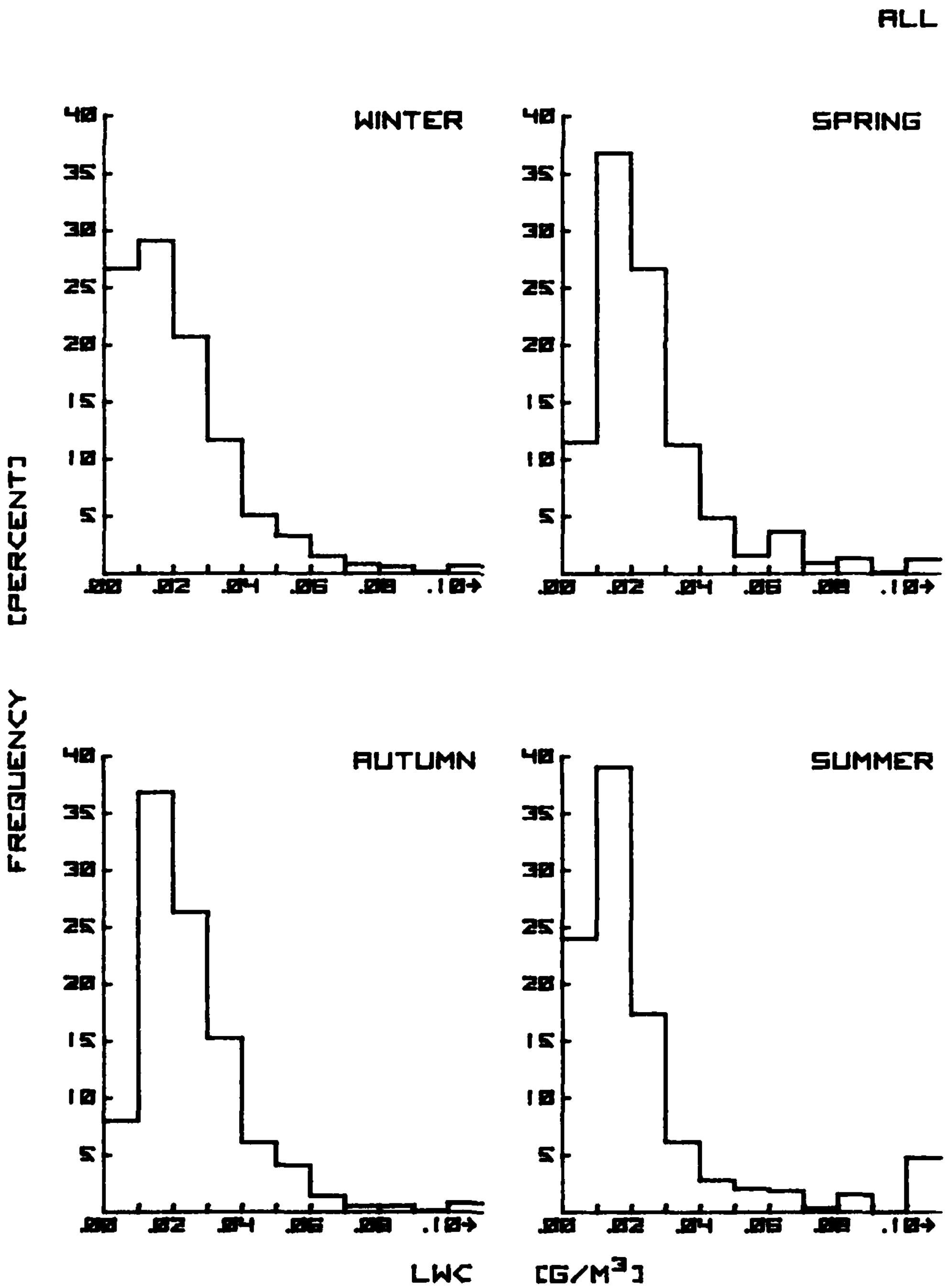

Figure 19ℓ. Seasonal Frequency Distribution of Liquid Water Content for All Stations

4. ANNUAL SUMMARY

4.1 Frequency of Cirrus

The 12-month percentage frequency of occurrence of cirriform clouds for each of the 11 stations and for all stations combined is shown in Figure 20. The annual mean for all stations was 50.5 percent. In the figure the stations are grouped by regions—western (five stations), central (three stations) and eastern (three stations). Within each group the stations are arranged by decreasing latitudes (only Semipalatinsk and Chita changed positions from the order used in all the preceding figures). The figure shows that, on an annual basis and within each group, there is a latitudinal variation in cirrus frequency. The figure also shows that high frequencies are found at the four stations—Murmansk, Perm, Chita and Semipalatinsk—at which they would be expected from the discussion in the previous sections. The lowest frequency is at Tashkent resulting from the very small number of cirrus occurrences in summer.

4.2 Cirrus Top and Base Heights

The 12-month average top and base heights of cirrus clouds for each station are shown in Figure 21. The 12-month average heights for all stations, with values of 9.2 km for the top and 7.2 km for the base, are also shown. Again, the stations are grouped by regions and arranged by latitudes within each group. The latitudinal effects on both the top and base heights are suggestive in this figure. Furthermore, the figure shows Murmansk, the most northern station, with the lowest cloud top and base and Tashkent, the most southern station, with the highest top and base heights. The average top and base heights of the stations are plotted against latitude in Figure 22. This figure shows that despite the extremely large longitudinal range, the average annual heights of both the cirrus top and base are a function of latitude, with the greatest heights being reached in the lower latitudes. Similar plots by seasons did not reveal such a well-defined latitudinal trend.

The frequency distribution of the heights of cirrus tops and bases for the 11 stations for the year are shown in Figures 23 and 24, respectively. Because of the tendency for the height estimates to be rounded off to the nearest 2000 ft as discussed previously, the frequency distribution is presented at 2000-ft intervals. The heights of the cloud tops extended from 13,000 to 45,000 ft, with the most frequently observed heights ranging from 30,000 to 34,000 ft. Cirrus with tops above 38,000 ft were practically negligible. The heights of the cloud bases ranged from 9000 to 38,000 ft, with the most frequently observed heights between 22,000 and 26,000 ft. Cirrus with bases at and above 32,000 ft amounted to less than 2 percent.

4.3 Cirrus Thickness

The 12-month average thicknesses for each station and for all stations combined are shown in Figure 25. The station grouping and arrangement are the same as the previous figures in this section. The average thickness for all stations was 2.0 km. With the exception of Chita, where the average thickness was 1.7 km, the average for the other stations ranged from 1.9 to 2.2 km. With such a small range of variation it can be said that no latitudinal trend is noted.

The cloud thickness-frequency distribution is presented in Figure 26. The frequencies are plotted from less than 1000 ft up to 20,000 ft at 1000-ft intervals. Although the thickness values ranged from 300 to 19,000 ft, the most frequent thicknesses of individual layers fall in the 4000 to 7000 ft range with a maximum from 5000 to 6000 ft.

4.4 Liquid Water Content of Cirrus

The 12-month average LWC values for each station and for all stations combined are plotted in Figure 27. The annual mean for all stations was 0.024 g/m^3. The most noticeable feature is the 0.046 g/m^3 value for Perm while for the others the values ranged from 0.016 to 0.026 g/m^3. No latitudinal trend of LWC is noted in this figure.

The frequency distribution of LWC of cirrus layers for all stations combined is shown in Figure 28. As with the similar seasonal plots, the most frequent LWC values were found between 0.01 and 0.02 g/m^3.

5. COMPARISON WITH AIRCRAFT OBSERVATIONS

Aircraft observations of cirriform clouds over the European part of the USSR are presented by Baranov.[4] The observations were made during the period from 1953 through 1958. A total of 1370 aircraft reports on high clouds were selected by Baranov. For comparison purposes the 11 AFGL-2 stations were reduced to the 5 stations in the European part of the USSR. The stations were Murmansk, Leningrad, Moscow, Kiev, and Simferopol. There were 7223 data sets on cirrus clouds for the five stations for the 12 months of 1973 and 1974. Although the duration and periods of observations were years apart, and most importantly, the observational techniques were completely different, the average heights of cloud tops and bases as well as the average cloud thickness for the region and for Leningrad will be compared.

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4. Baranov, A.M. (1965) The thickness of high clouds and the annual variation of the height of their tops. Studies of Clouds, Precipitation, and Thunderstorm Electricity, Translation, American Meteorological Society, Boston, Mass.

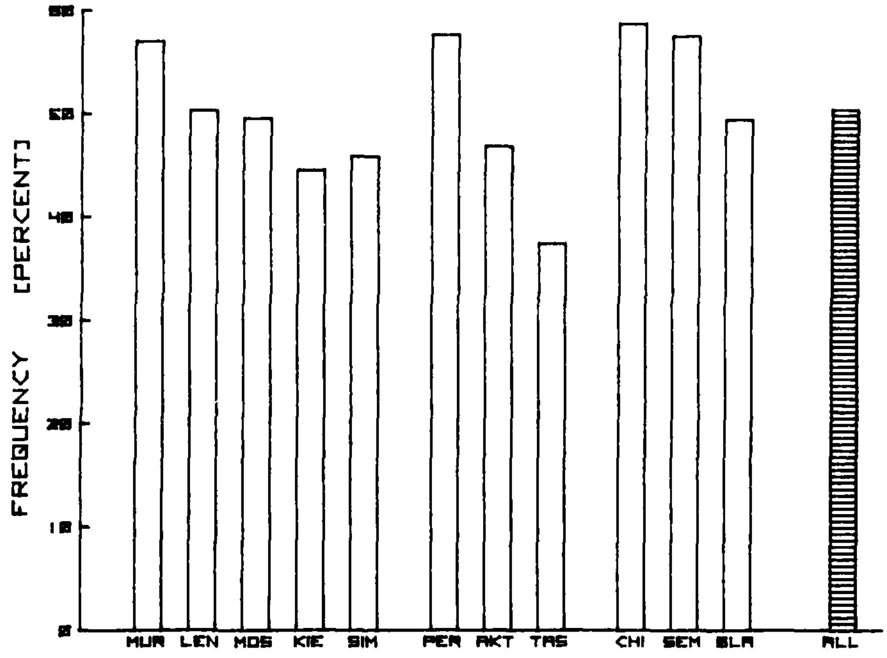

Figure 20. Annual Percentage Frequency of Cirriform Cloud Occurrence

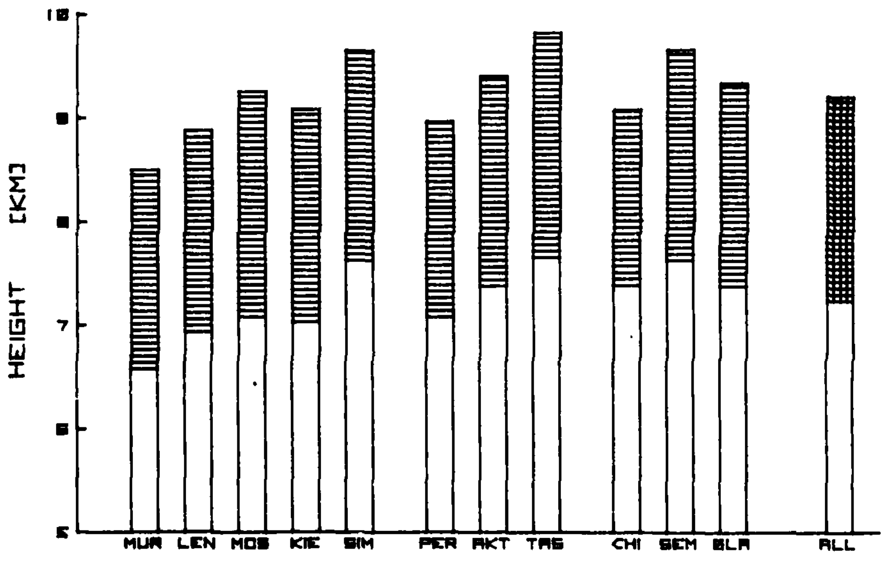

Figure 21. Annual Average Top and Base Heights of Cirriform Cloud Layers

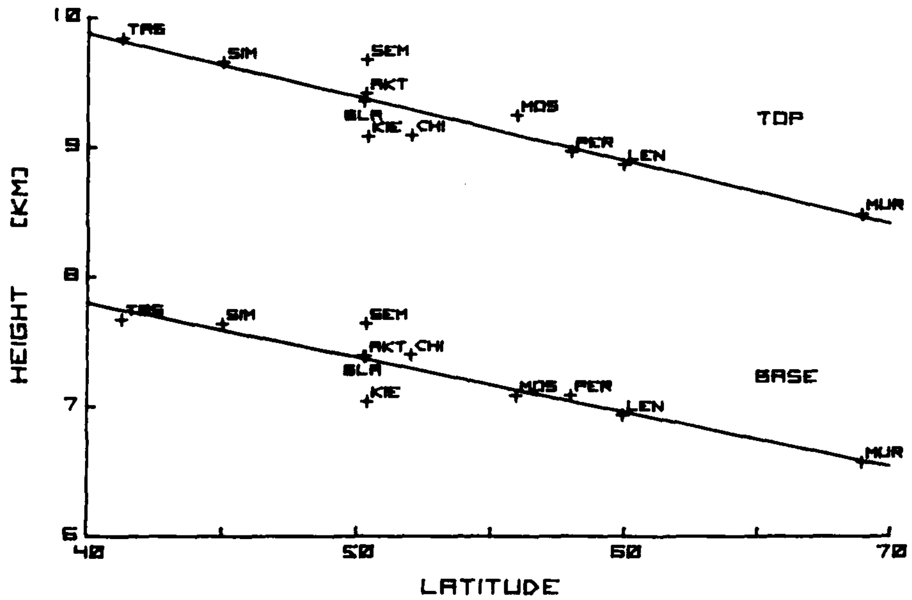

Figure 22. Latitudinal Variation of Average Top and Base Heights of Cirriform Cloud Layers

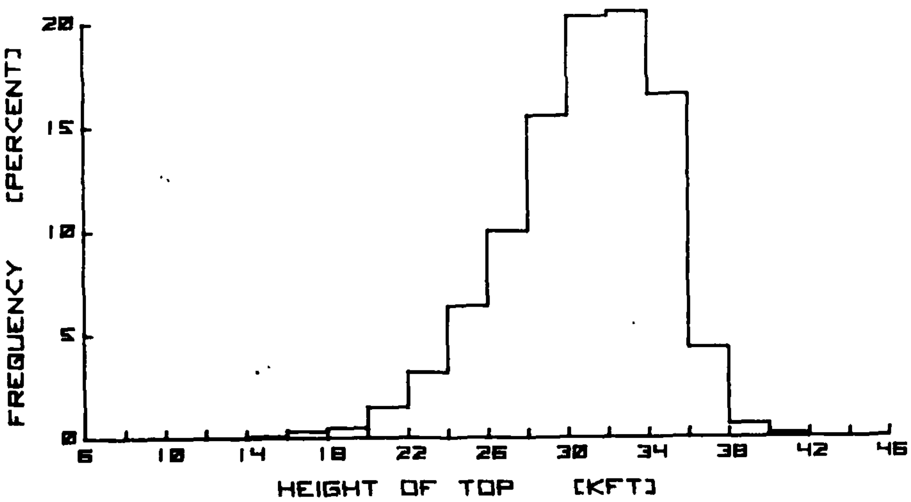

Figure 23. Annual Frequency Distribution of Heights of Cirriform Cloud Tops for All Stations

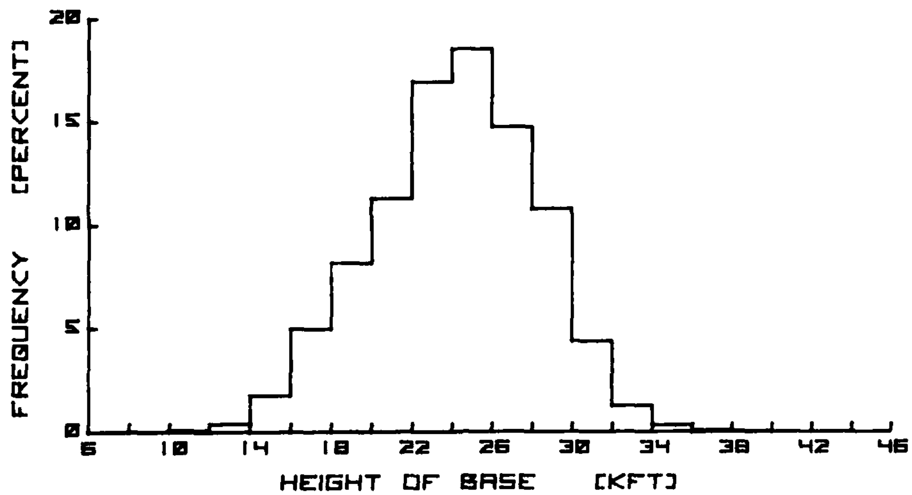

Figure 24. Annual Frequency Distribution of Heights of Cirriform Cloud Bases for All Stations

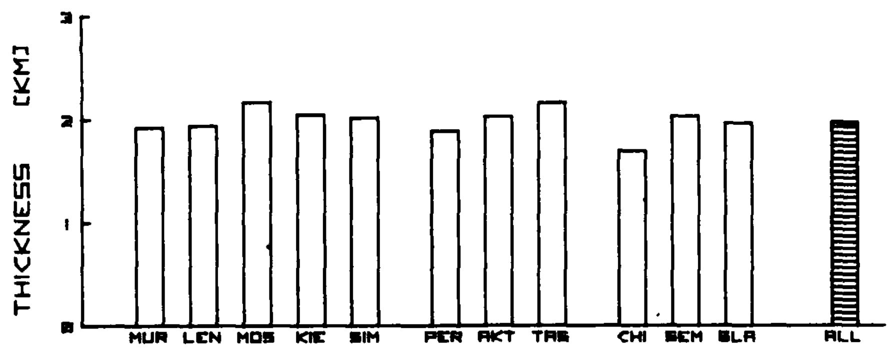

Figure 25. Annual Average Thickness of Cirriform Cloud Layers

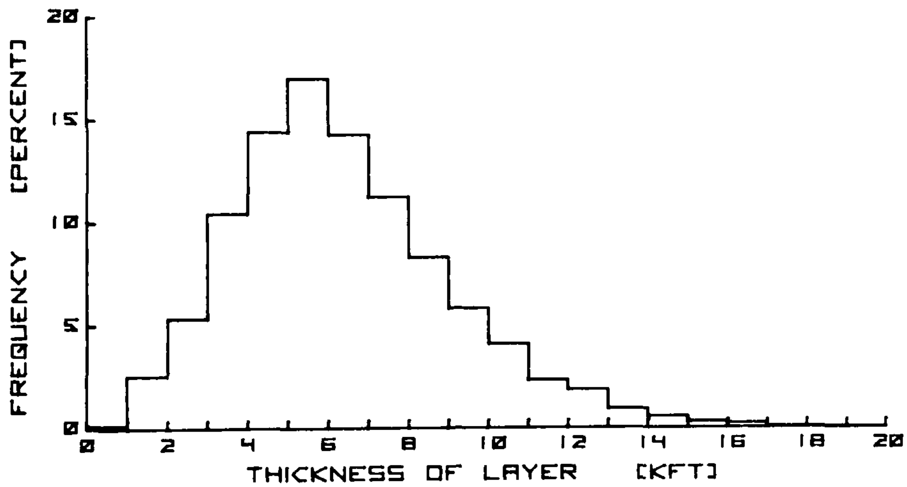

Figure 26. Annual Frequency Distribution of Cirriform Cloud Layer Thickness for All Stations

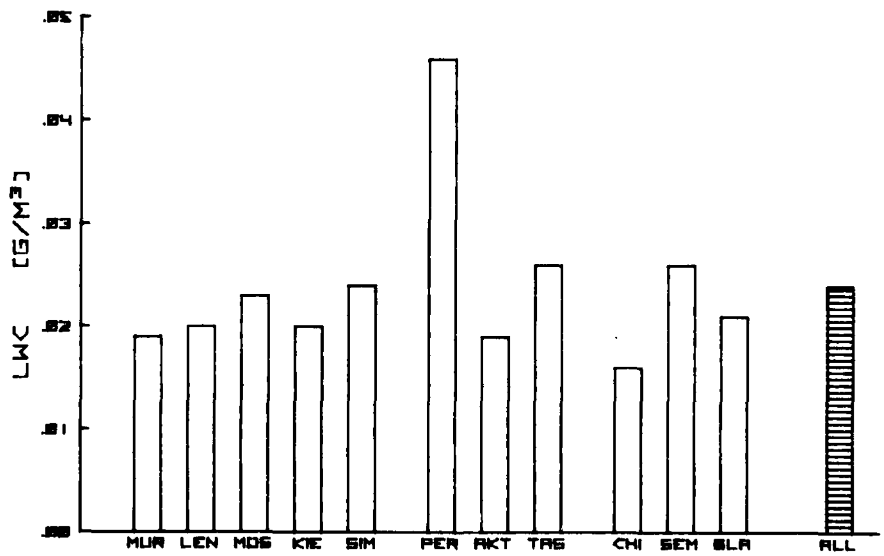

Figure 27. Annual Average Liquid Water Content Values of Cirriform Cloud Layers

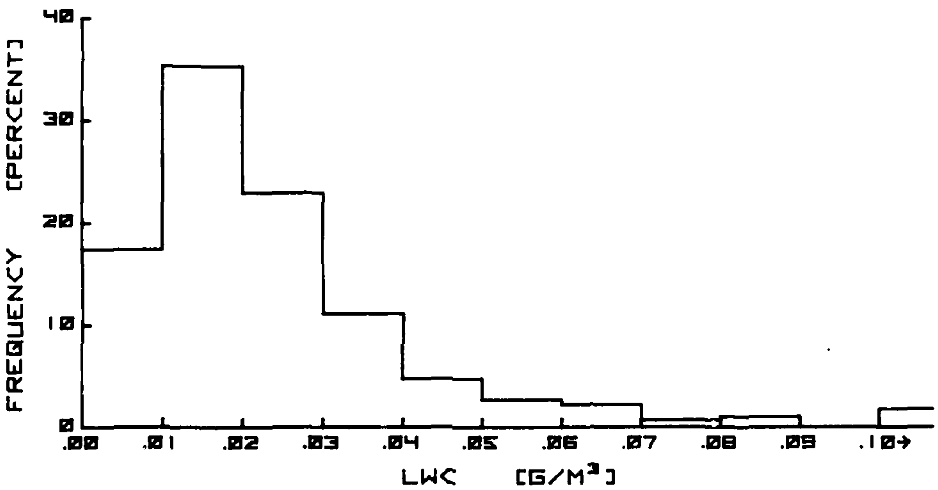

Figure 28. Annual Frequency Distribution of Liquid Water Content for All Stations

Figure 29 compares the seasonal average top and base heights and thicknesses of the cirrus clouds obtained from the AFGL-2 five-station data and from the aircraft data. The most obvious difference is noted in summer with the AFGL-2 top being 0.5 km and the base 0.8 km higher than the aircraft data. The difference in summer is also evident for the thickness. When averaged over the four seasons, the five-station values were 9.1 km for the top height, 7.1 km for the base height, and 2.0 km for the thickness. The weighted averages of the aircraft data for the four seasons were 9.0 km for the top, 6.9 km for the base, and 2.2 km for the thickness. Thus, on the average the overall differences did not exceed 0.2 km.

Figure 30 compares the AFGL-2 and aircraft seasonal averages for Leningrad. These averages were based on a total of 1470 sets of data for AFGL-2 and a total of 459 for the aircraft. The figure shows that only in summer do the top and base heights of the AFGL-2 data exceed the aircraft data, with the top only slightly higher but the base 1 km higher. The AFGL-2 data show more variability in cloud thickness, with differences of 0.3 km and 0.4 km less than the aircraft data in winter and in summer, respectively. The AFGL-2 averages over the four seasons were 8.9 km for the top, 6.9 km for the base, and 1.9 km for the thickness. Compared to these the weighted averages of the aircraft data were 9.1 km for the top, 7.0 km for the base, and 2.1 km for the thickness. Again, the overall differences did not exceed 0.2 km.

The differences between the AFGL-2 and aircraft data become more obvious when the frequency distributions of the heights of cirrus tops and bases and the thicknesses are compared. Figures 31, 32, and 33 show in order the distribution of the top heights, the base heights, and the thicknesses for the European part of the USSR and in Figures 34, 35, and 36 for Leningrad. The figures for the top heights and the thicknesses show that the AFGL-2 distributions tend to be more peaked and that the aircraft distributions more flat topped, resulting in higher maximum frequencies for the AFGL-2 data. On the other hand, the figures from the distribution of heights of bases show similar characteristic shapes with maximum frequencies of similar magnitudes. The height and thickness intervals of the maximum frequencies for all the parameters do not always agree, but the disagreement is almost always less than 1 km.

The above results are summarized in the form of annual frequency distribution of the parameters for the European part of the USSR and for Leningrad in Figure 37 for the top heights, Figure 38 for the base heights, and Figure 39 for the thicknesses. Except for the AFGL-2 cloud-top height distribution, the figures show that the distributions exhibited by Leningrad are very similar to those for the European part of the USSR for both AFGL-2 and aircraft data. The aircraft data show slightly higher maximum frequencies only for the base heights, but the heights and thicknesses of maximum frequencies for these sets of data are the same.

This brief comparison study show that, although the AFGL-2 and aircraft data are not in full agreement, showing differences which can be attributable to the different observational techniques and other factors, the two sets of data are compatible with one another.

6. CONCLUSIONS

The 11-station study of cirriform clouds for the 12-month period shows that the overall frequency of occurrence is slightly over 50 percent. These high clouds are found to occur most frequently in spring and the least frequently in summer. Within the area covered by the 11 stations, cirrus are more prevalent along the northeastern perimeter of the area. Only by subdividing the stations into three regions was it possible to show that within each region the cirrus frequency diminishes with decreasing latitude.

The average heights of cirrus tops and bases are found to be functions of season and latitude. The greatest heights are reached in summer and the lowest in winter. When averaged over all seasons, the heights of both the top and base are shown to decrease with increasing latitude. Plots of height variations vs the amount of cloud cover reveal that the top heights vary little with cloudiness but that the base heights decrease with increasing cloudiness. This leads to the conclusion that the thickness of cirrus layers increases with increasing cloudiness. Averaged over all stations and all seasons, the thickness was found to be 2.0 km. Cirrus layers are thickest in autumn and spring and thinnest in summer, but the difference is very small.

The range of LWC values of the cirrus layers can be extremely large. In this study the LWC value was highest in summer due to the very large values encountered at a few stations and was the lowest in winter.

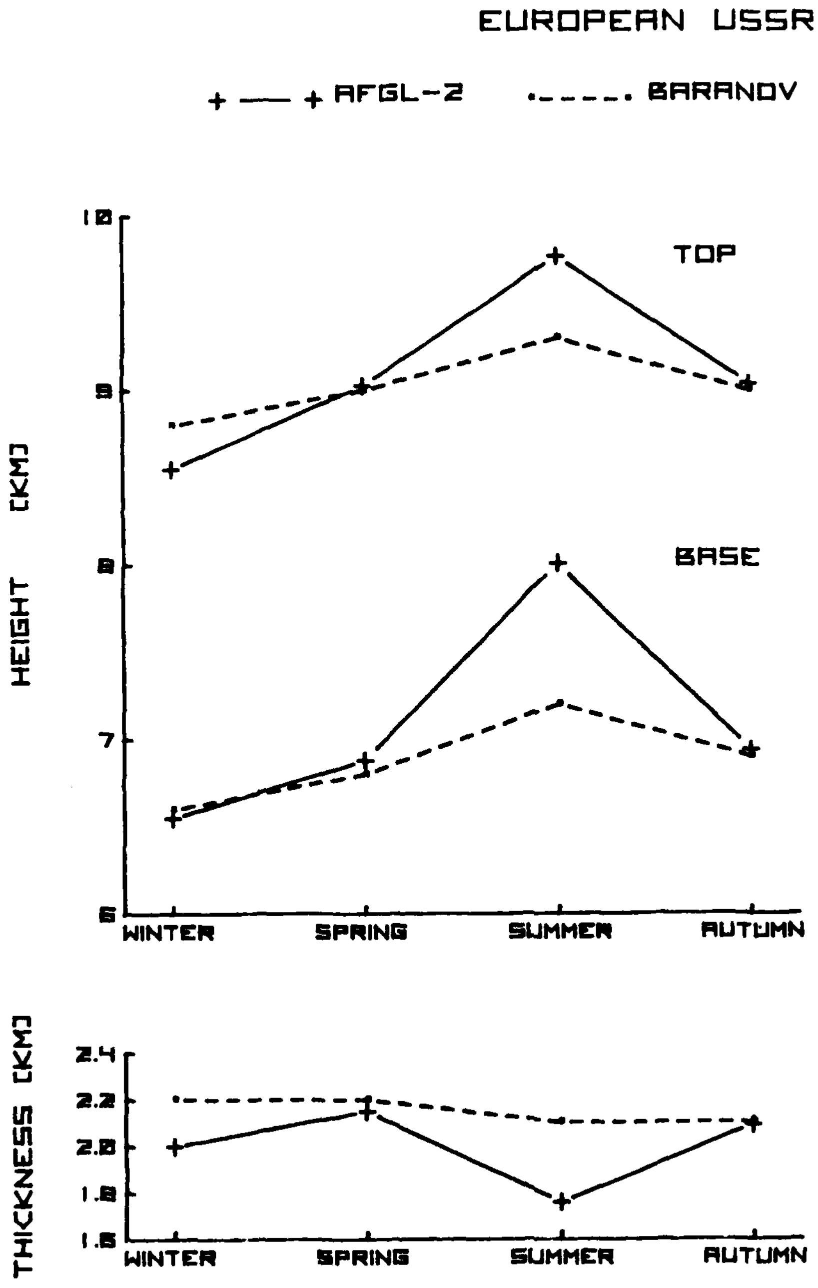

Figure 29. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Average Heights of Tops and Bases and Thicknesses for the European Part of the USSR

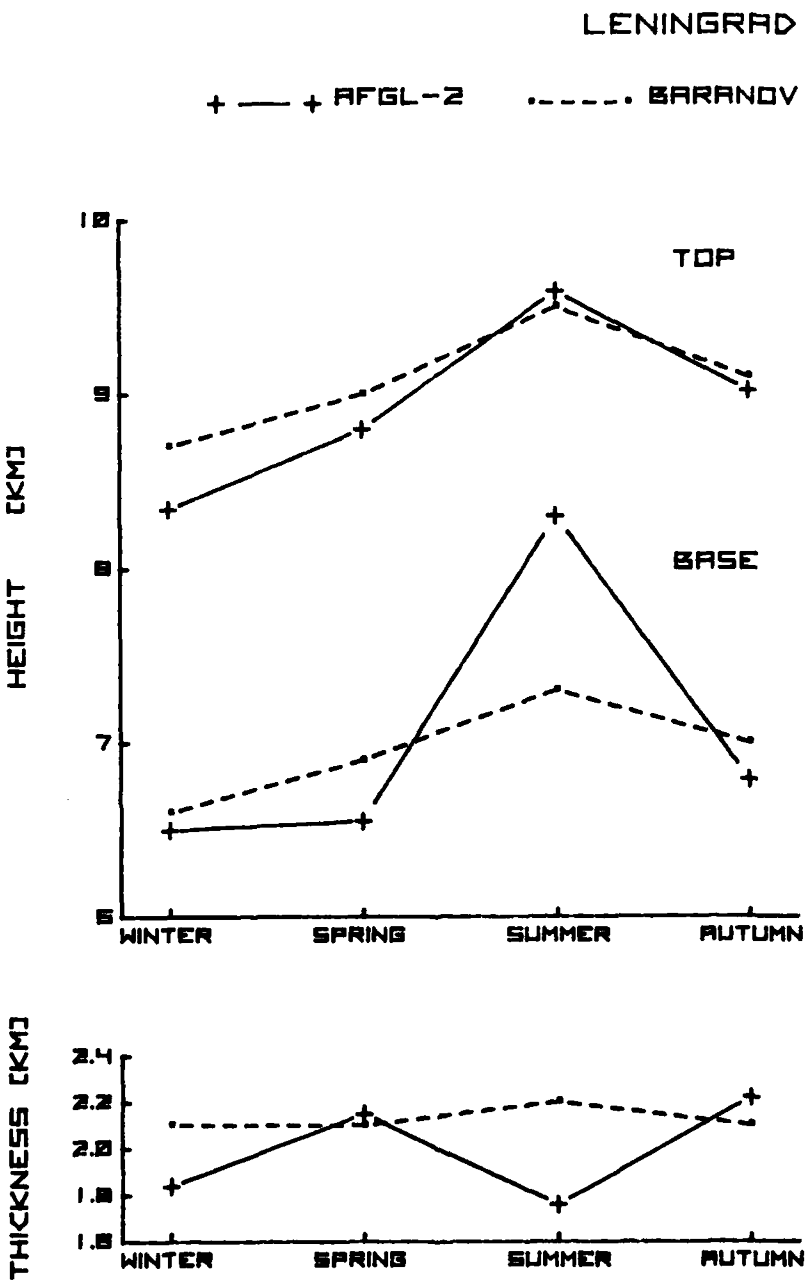

Figure 30. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Average Heights of Tops and Bases and Thicknesses for Leningrad

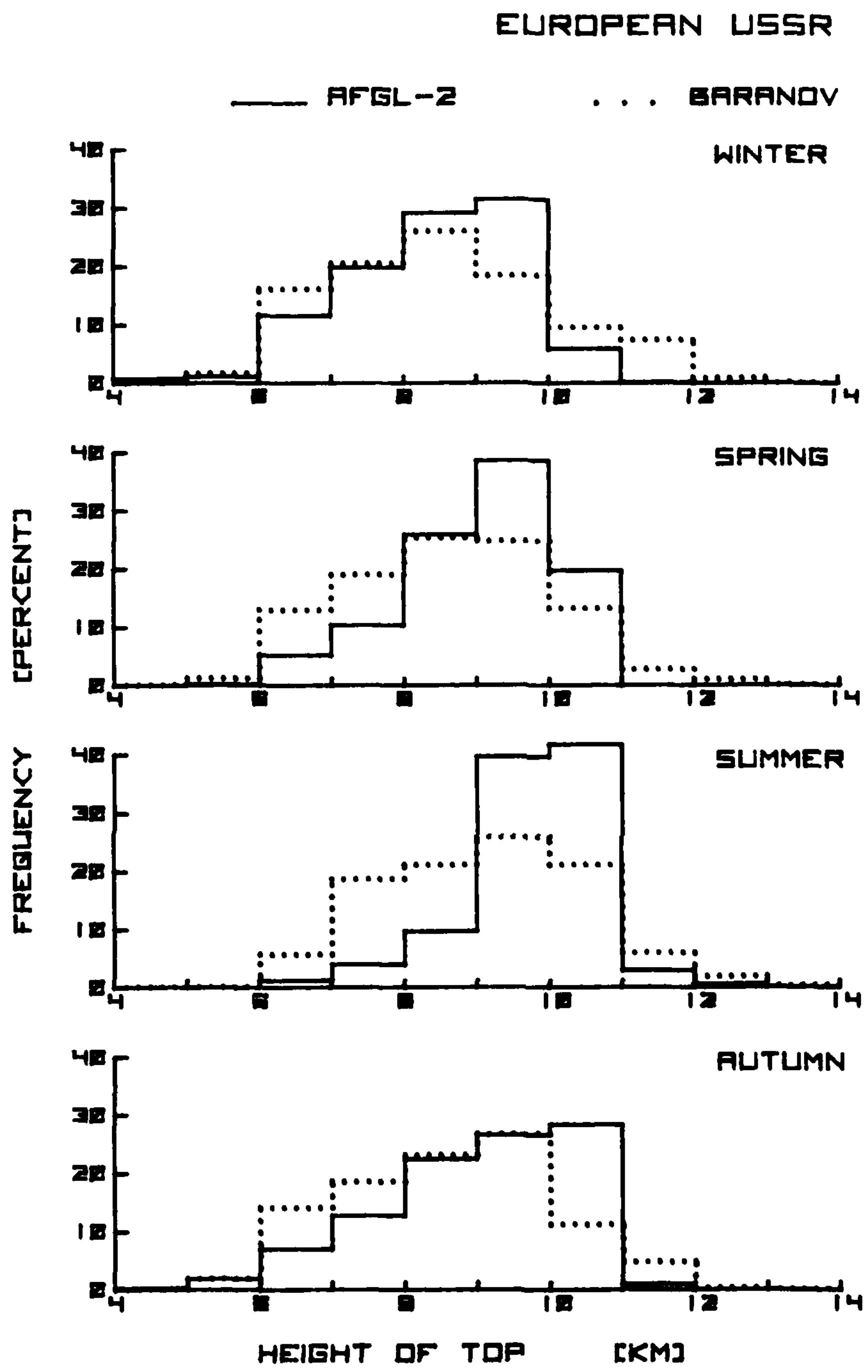

Figure 31. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Frequency Distribution of Heights of Tops for the European Part of the USSR

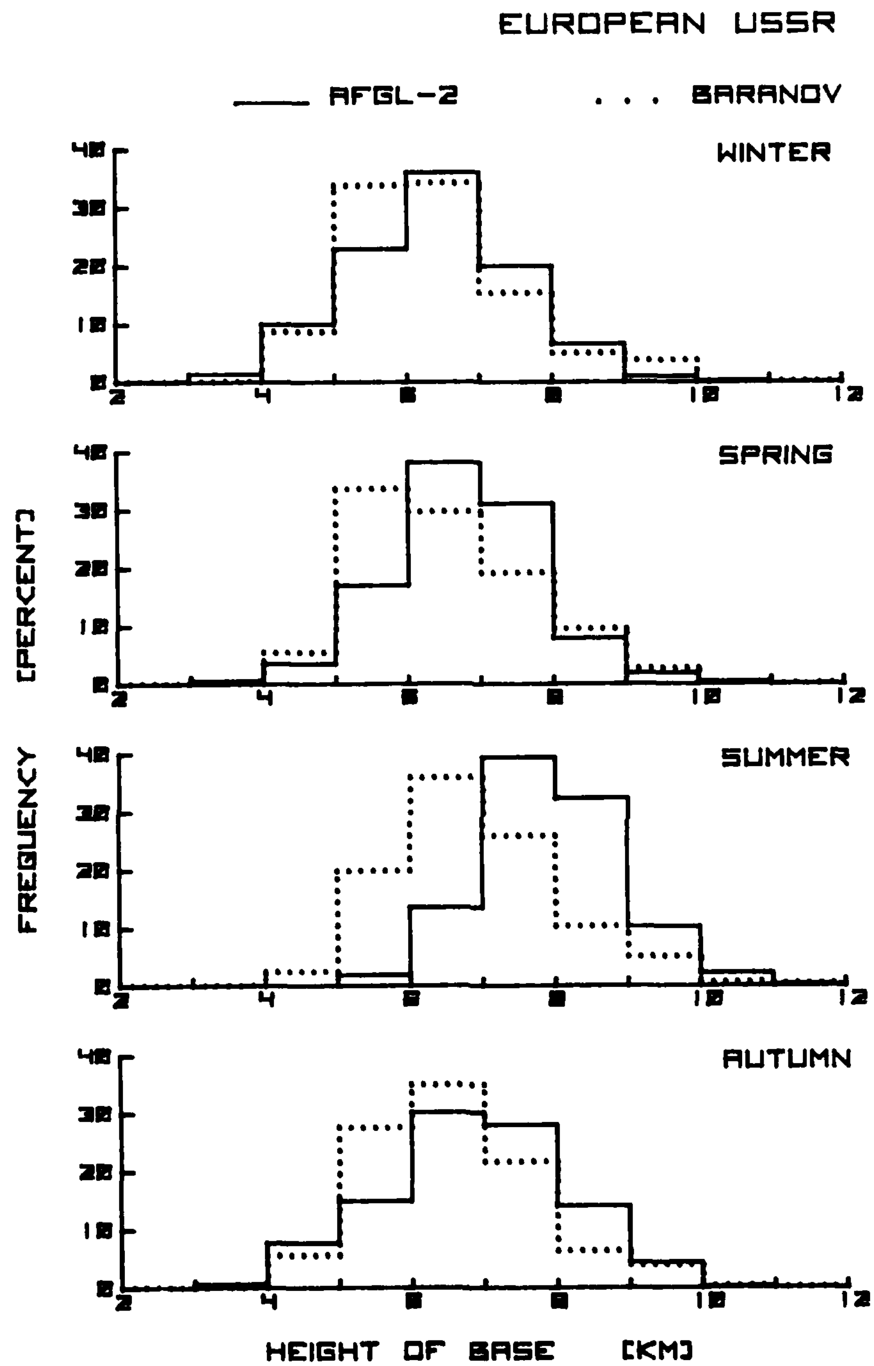

Figure 32. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Frequency Distribution of Heights of Bases for the European Part of the USSR

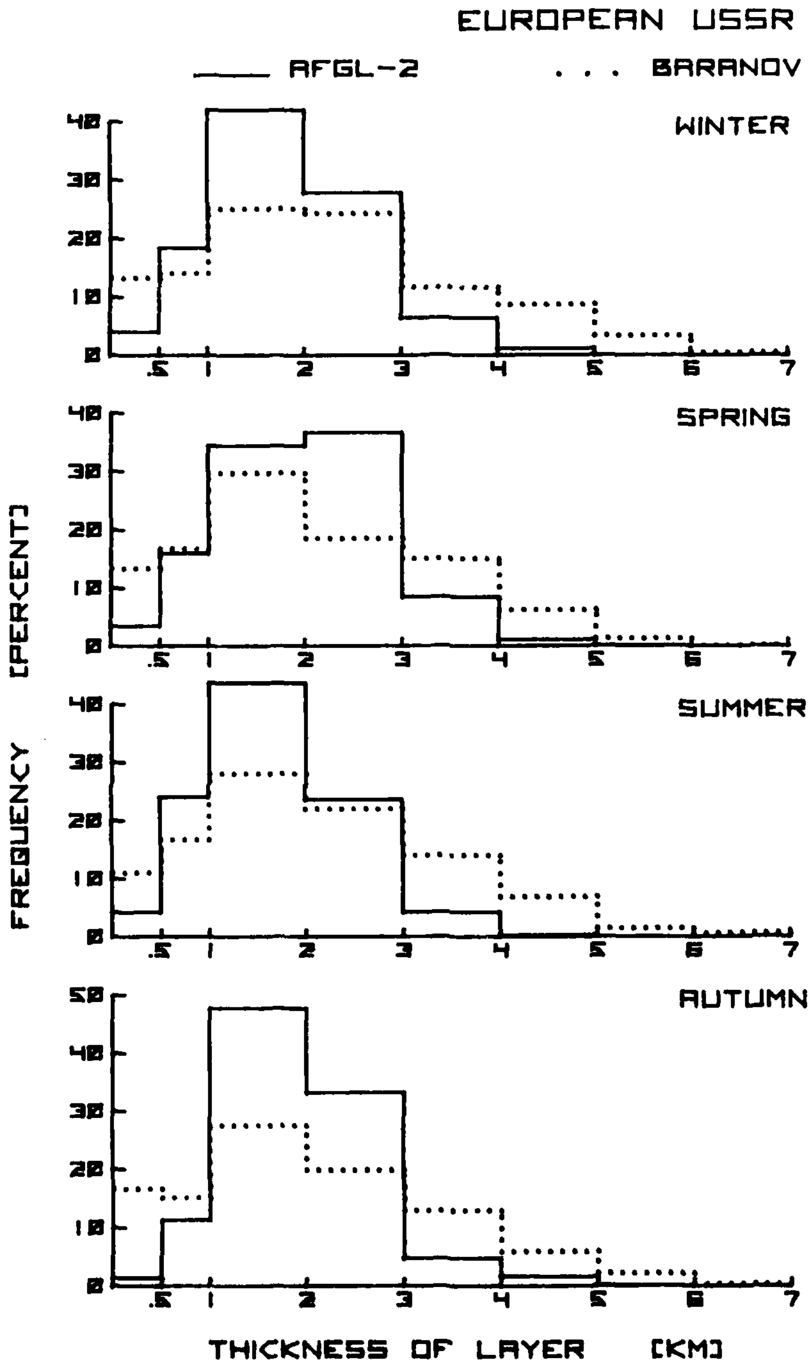

Figure 33. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Frequency Distribution of Thickness for the European Part of the USSR

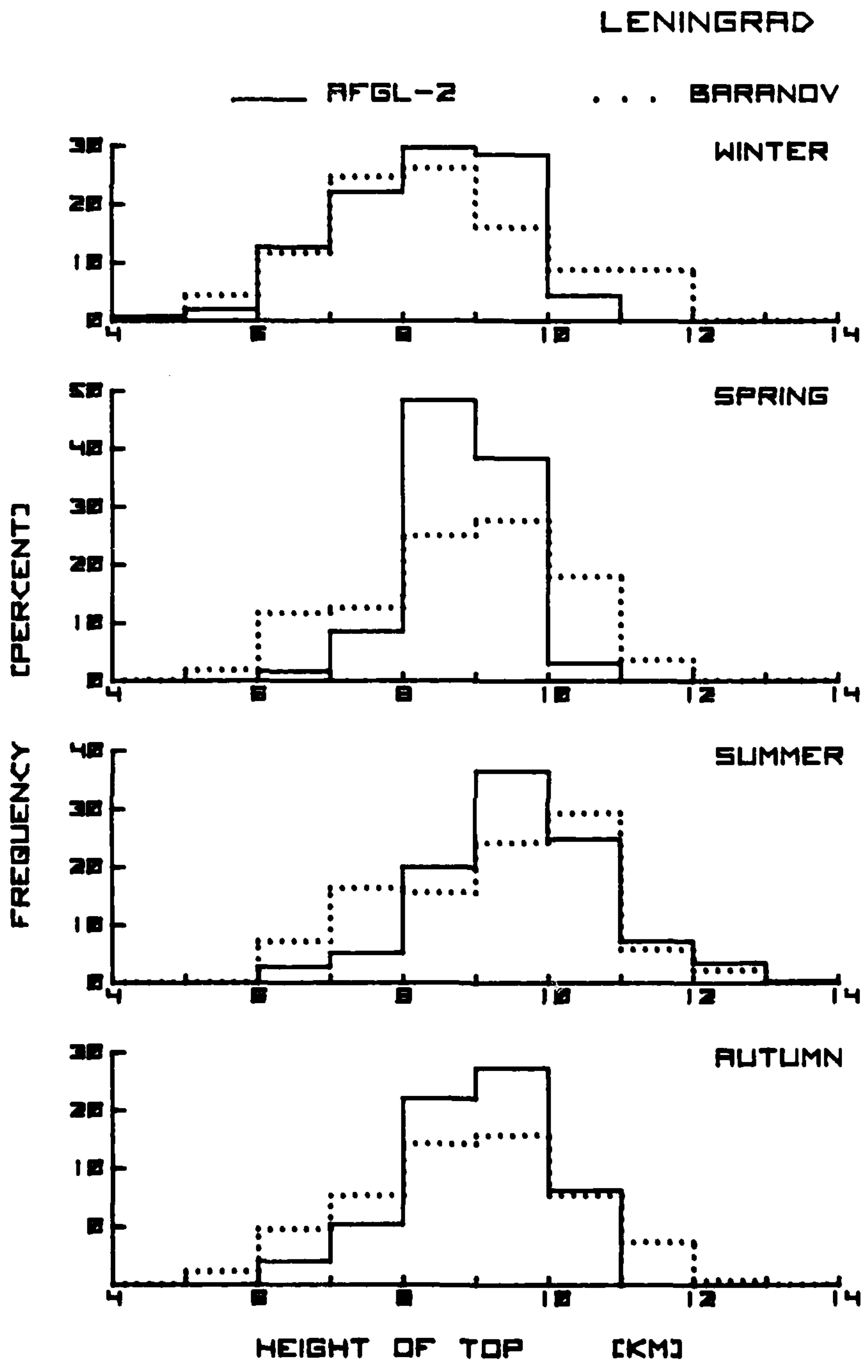

Figure 34. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Frequency Distribution of Heights of Tops for Leningrad

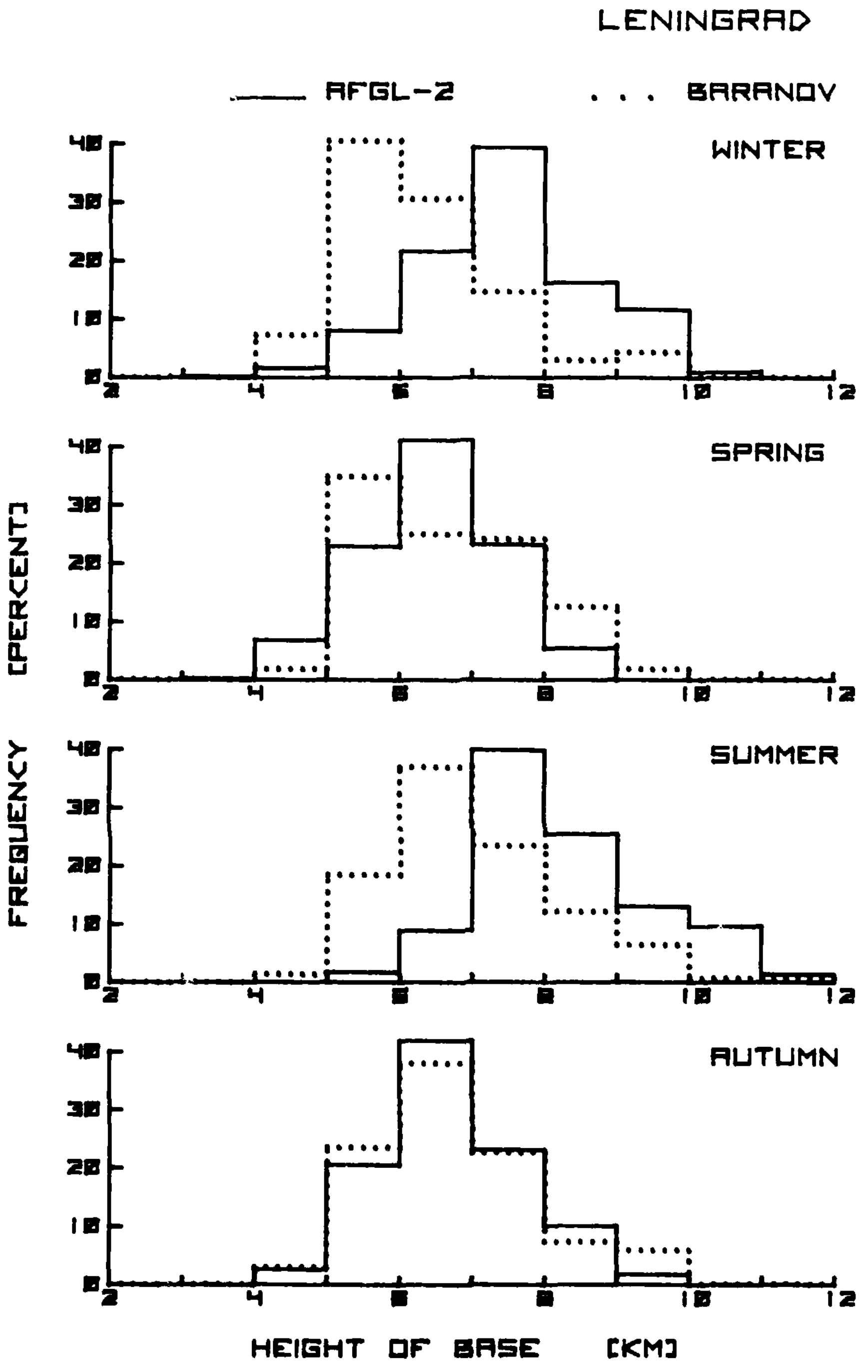

Figure 35. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Frequency Distribution of Heights of Bases for Leningrad

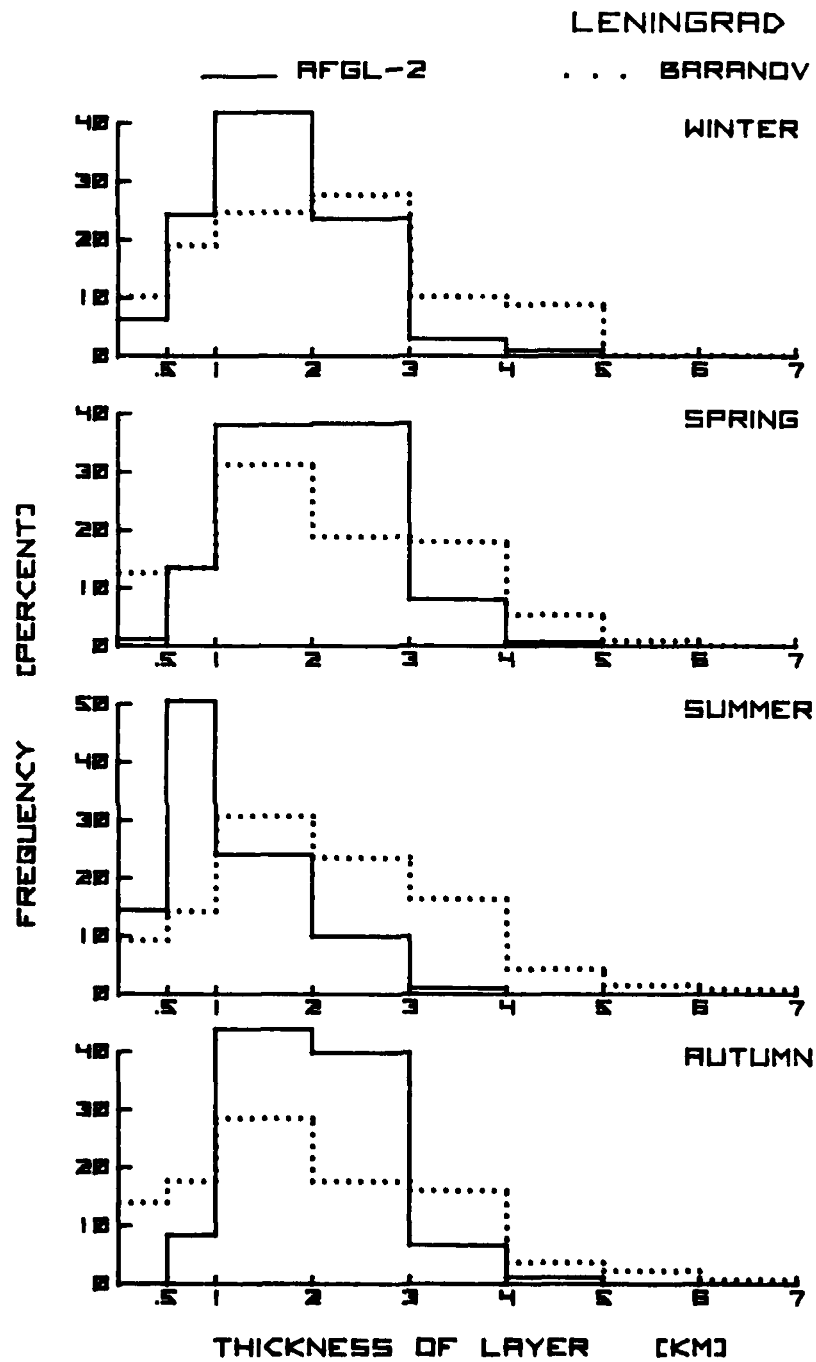

Figure 36. Comparison of AFGL-2 and Aircraft Observations in Terms of Seasonal Frequency Distribution of Thicknesses for Leningrad

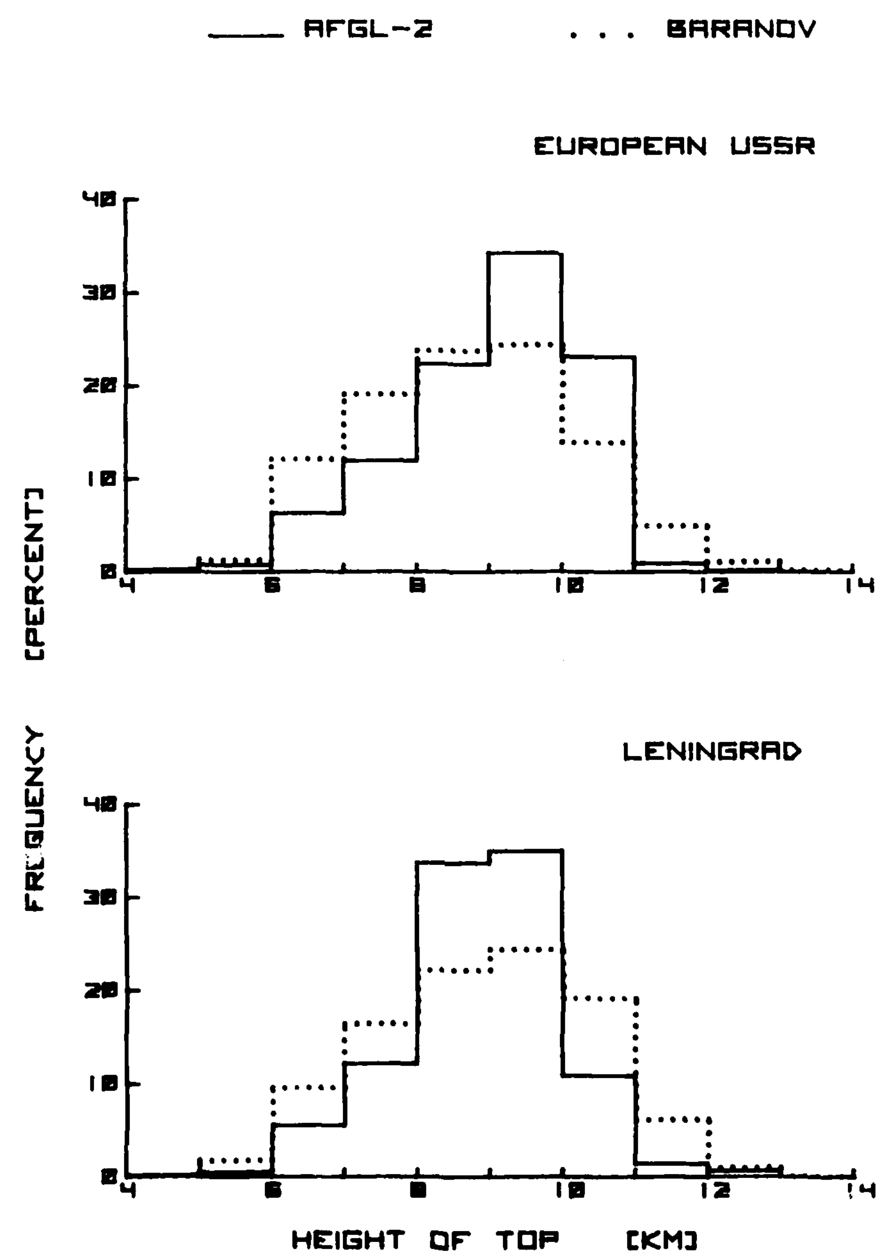

Figure 37. Comparison of AFGL-2 and Aircraft Observations in Terms of Annual Frequency Distribution of Heights of Tops for the European Part of the USSR and for Leningrad

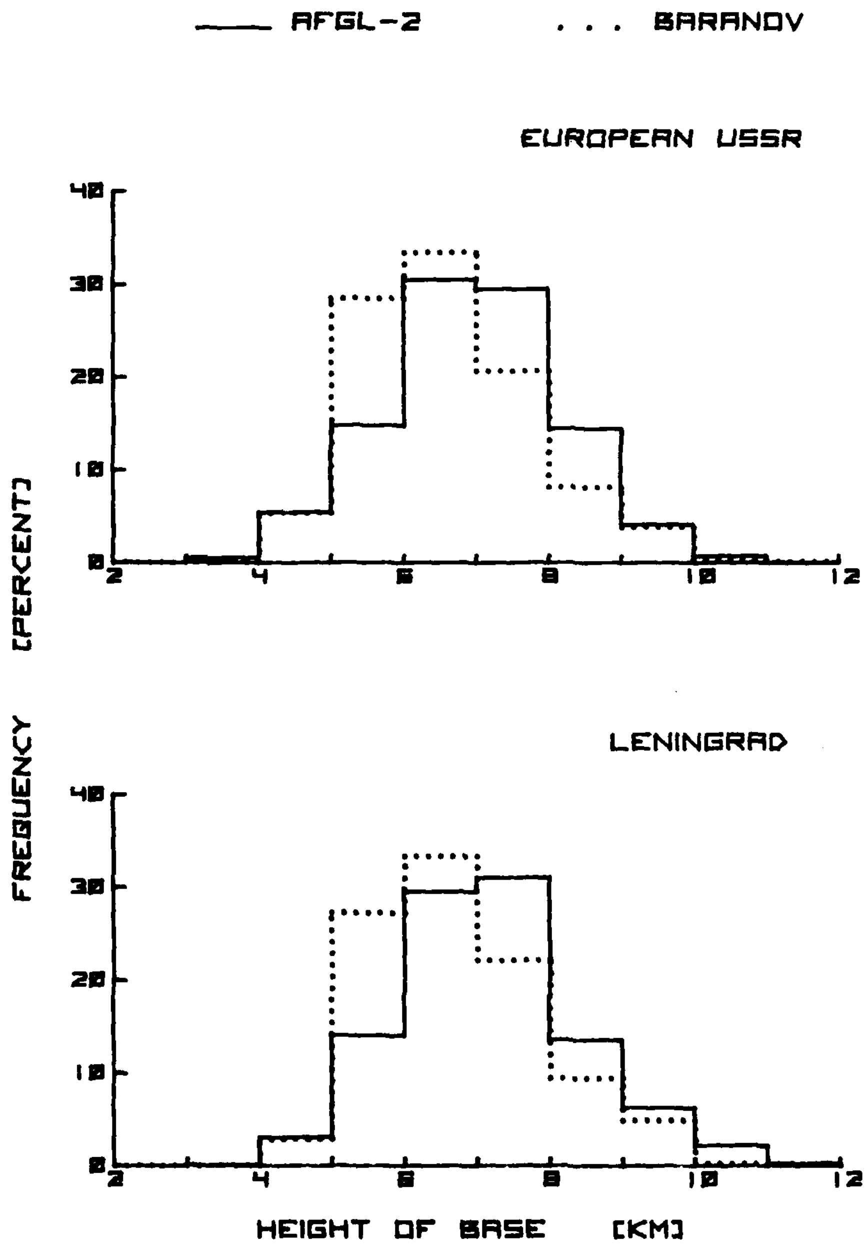

Figure 38. Comparison of AFGL-2 and Aircraft Observations in Terms of Annual Frequency Distribution of Heights of Bases for the European Part of the USSR and for Leningrad

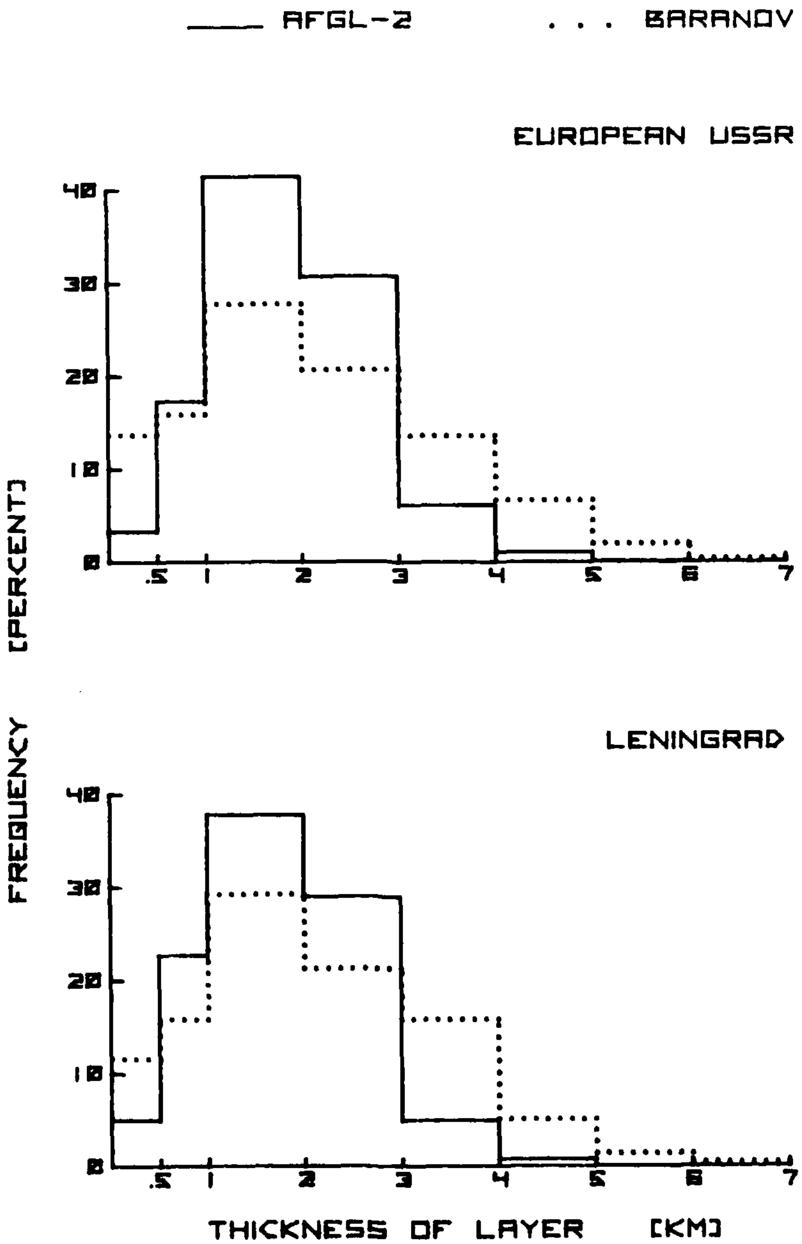

Figure 39. Comparison of AFGL-2 and Aircraft Observations in Terms of Annual Frequency Distribution of Thicknesses for the European Part of the USSR and for Leningrad